7. 2002 DATA EVALUATION

This section presents an analysis of groundwater data that were collected through 2002 to support the monitored natural attenuation (MNA) remedial action component. The results of this data evaluation document baseline conditions prior to the start of the MNA remedial action. Section 7.1 summarizes the objectives of this data evaluation; Section 7.2 presents an analysis of TCE data; Section 7.3 presents an analysis of radionuclide data; and Section 7.4 provides a summary of water level data.

7.1 Objectives for Evaluation of 2002 Data

The MNA Remedial Action Work Plan (RAWP) (DOE-ID 2003a) provides a comprehensive plan for continued performance monitoring and compliance monitoring during the MNA remedial action. Progress toward meeting the objectives identified in the RAWP will be evaluated periodically throughout the 100-year operational period of the remedy. Monitoring data will be analyzed and reported annually during performance operations, and at a frequency to be determined for the duration of long-term operations.

To support upcoming evaluation and reporting during the MNA remedial action, data analysis activities were conducted and are reported in this section. These activities serve to document pre-remedial action operational conditions and will support hture interpretation of the monitoring data. The data analysis activities included in this report are listed below.

1. Evaluate baseline TCE concentrations and trends
2. Document observed degradation rate constants and half-lives for TCE and cis-DCE
3. Summarize results of vertical profile samples collected using FLUTe™ liners
4. Document the basis for the current estimate of the preoperational TCE plume boundaries
5. Document numerical model verification and update work
6. Evaluate baseline radionuclide concentrations and trends
7. Examine inherent variability observed in the VOC and radionuclide data
8. Summarize results of water level data.

7.2 Analysis of Trichloroethene Data

Multiple VOC constituents are identified as COCs for the MNA remedy (i.e., TCE, PCE, cis-DCE, and trans-1, 2-Dichloroethene [trans-DCE]; DOE-ID 2001). TCE is of primary interest, as it was disposed of in the greatest quantity and is most prevalent in the extended plume. This section will discuss TCE concentrations from selected wells.

7.2.1 Historical Trichloroethene Concentrations in Monitored Natural Attenuation Wells

In this section, 2002 data and historical TCE data are analyzed to describe baseline conditions prior to the start of MNA remedial action operations. Five wells were selected to represent pre-remedial action concentrations throughout the distal zone of the plume. These five wells include TAN-48, located downgradient of the medial zone; TAN-16 and TAN-21, located near the western and eastern plume edges, respectively; and ANP-8 and GIN-2, located near the toe of the plume. Because some wells were

sampled multiple times during a year, annual averages (calendar year) were constructed and used in this analysis to avoid biasing the results. Future MNA performance monitoring will be conducted on a consistent, annual basis.

TCE concentrations at TAN-48 show decreasing annual averages from 550 µg/L in 1998 to 398 µg/L in 2000. Concentrations for TAN-16, TAN-21, and ANP-8 are plotted in Figure 7-1. Data from TAN-21 and ANP-8 are relatively constant, with recent concentrations within 10 µg/L of those measured during the 1990s. This is consistent with modeled predictions, as peak breakthrough is not expected at these wells for at least another decade (Martian 2002). Data from TAN-16 also are consistent with numerical model results that predict a gradual peak in concentration between 1995 and 2010 (Martian 2002). Although recent measurements are lower than those measured in the 1997-1998 timeframe, additional years of data will be necessary before peak breakthrough can be verified. Trichloroethene concentrations at GIN-2 have consistently been below the 5 µg/L maximum contaminant level (MCL) for TCE from 1997 through 2002.

Trichloroethene concentrations for five wells located near the downgradient boundary of the medial zone are plotted in Figure 7-2. Due to the effects of NPTF operations, data in this area since October 2001 are unreliable for assessing natural degradation trends. Additional data collected after NPTF operations have been completed may be used to support hture trend analysis. However, one conclusion that can be drawn from the available pre-NPTF operations data is that concentrations in this area were consistently less than 1,000 µg/L, indicating that groundwater in this area would be within the operational limits defined for the MNA component of the remedy.

7.2.2 Methodology for Trend Testing

Because trend testing will be an important tool used to evaluate hture MNA performance, it is of interest to determine whether trends are readily distinguishable in the TCE data. This section describes the analysis of trends in data from one well using a linear regression technique.

The identification of meaninghl trends in environmental data can be problematic. A statistically significant trend, that is when the true slope of the data over time is different from zero, can be difficult to distinguish from random variability, cyclical fluctuations, and other features common in groundwater data. A number of statistical techniques are recommended for identification of trends in MNA monitoring data (EPA 1999; DOE 1999). These include application of a standard linear regression model, as well as nonparametric methods including the Sen slope test and hypothesis testing using the Mann-Kendall statistic. Smoothing approaches may also be appropriate if short-scale variability in the data mask longer-term trends.

At this time, data sufficient to support trend analysis are only available at a few wells. Arrival of center of mass (peak breakthrough) is not expected to have occurred at the distal zone monitoring well locations, but several wells located in the medial zone are 18 or more years past breakthrough (as predicted by numerical modeling). These wells and their predicted breakthrough peaks consist of

- TAN-40 (predicted peak 1976)
- TAN-32 (predicted peak 1978)
- USGS-24 (predicted peak 1978)
- TAN-36 (predicted peak 1981)
- TAN-D1 (predicted peak 1983).

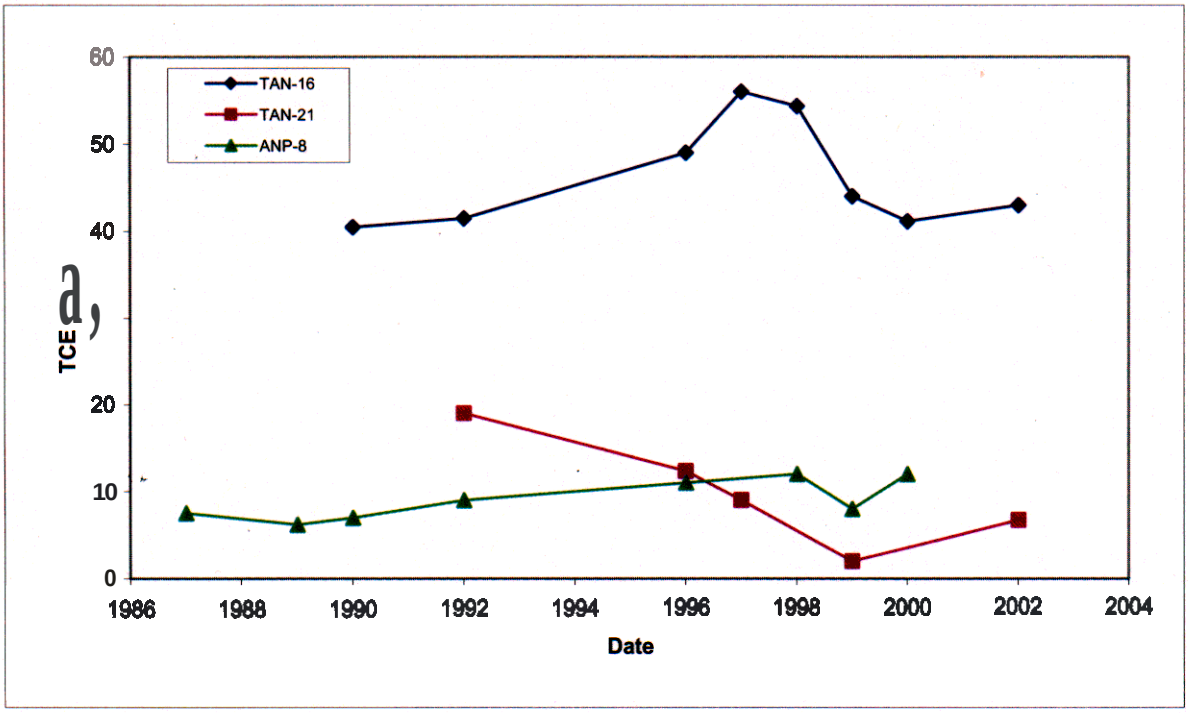

Figure 7-1. Trichloroethene concentrations for selected distal zone monitoring wells (plotted as annual averages).

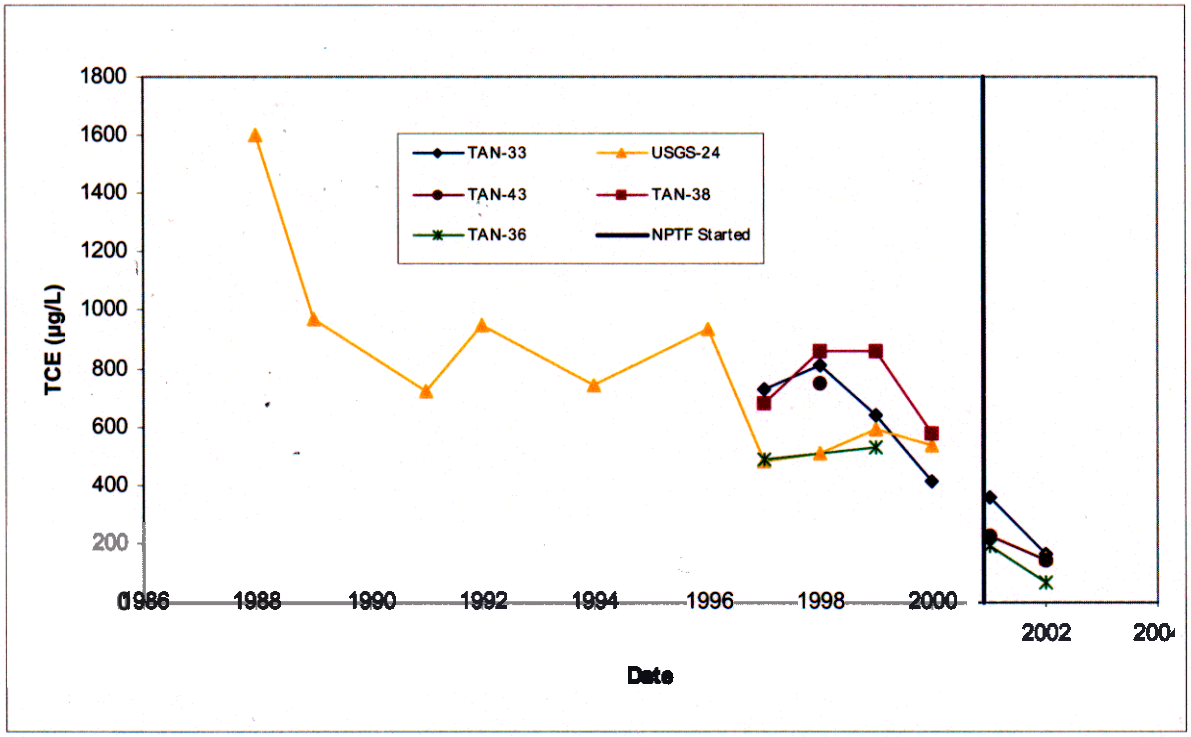

Figure 7-2. Trichloroethene concentrations for selected medial zone monitoring wells (plotted as annual averages).

Of these five wells, TAN-40, TAN-36, and TAN-32 have only been sampled for a few years and have insufficient data for trend analysis. Additionally, the 2001 and 2002 concentrations at TAN-32, TAN-36, and USGS-24 have probably been influenced by NPTF operations, rendering data collected from these three locations after October 2001 unusable for assessing trends. The NPTF began full-scale operations in October 2001 and data were collected from these wells in December 2001. TAN-D1 has an extensive set of data available prior to the start of NPTF operations, but because it is a stormwater drainage well and may be influenced by annual precipitation recharges, data from that location would not be representative of degradation trends. However, USGS-24 has a substantial set of data and is not known to have been influenced by any operations prior to the start of the NPTF; therefore, it was used to illustrate a trend analysis approach.

Trichloroethene concentrations measured at USGS-24 are plotted over time in Figure 7-3, with the start of the NPTF indicated on the graph. Annual averages are used when more than one sample was analyzed in a given calendar year. The plot of the USGS-24 data, prior to the start of the NPTF, suggests that the data might be fit with a linear regression. However, the linear regression model is only meaninghl when its underlying statistical assumptions are met. That is, the data need to follow a normal (or approximately normal) distribution. The regression residuals also need to be normally distributed and have constant variance, and the data cannot be serially correlated (that is, each measurement needs to be independent (EPA 2000).

To verify these assumptions, the USGS-24 data set between 1988 and 2000 were first tested for normality using the Shapiro-Wilks test of normality. The test yielded a W Statistic of 0.84, which demonstrated that the data are normally distributed at a 99% level of significance. Because each datum represented a year or more, there was no reason to believe the data were serially correlated. Therefore, a linear regression was fit to the data, and the regression residuals (the differences between the regression model line and actual data points) were hrther tested. Application of the Shapiro-Wilks test to the residuals indicated that they were also normally distributed at a 99% level of significance (W Statistic of 0.92). This result indicates that the estimation error, that is the difference between the regression model and the observed points, was relatively constant over time. The mean of the residuals was –3.30E-12, which, because it is so close to zero, indicates that the data are not biased; that is, the errors are evenly distributed above and below the regression line. These checks indicated that the assumptions underlying the linear regression model were met by this set of data and that results of a linear regression would be meaninghl.

The regression line and equation are illustrated in Figure 7-3. The slope of the line is –63, indicating that the TCE concentrations at this location have been decreasing at a rate of approximately 63 µg/L/year. Although there is substantial scatter about the regression line, the coefficient of determination, denoted by R^2, is 0.63, which indicates that 63% of the variability in the data is accounted for by the regression model. In practice, a value of R^2 of 0.60 or greater is usually considered to be high, and thus, an indicator that the model provides a good fit to the data (EPA 1992).

The results of this analysis indicate that TCE trends at this location are consistent with numerical model predictions. Breakthrough has already occurred at this location, and TCE concentrations have been decreasing steadily over the last decade. The analysis also indicates that a meaninghl trend is discernable in the post-breakthrough TCE data set at this location. However, it is important to note that although the USGS-24 data exhibit a readily identified trend, hture data from other distal zone monitoring wells may not be as amenable to this type of analysis. Because of the proximity of USGS-24 to TSF-05, TCE concentrations at that location have historically been very high and dispersion is small. Both of these factors are thought to cause a relatively sharp peak in concentration followed by a steep downward trend. Locations hrther downgradient are expected to have lower and broader concentration peaks with very

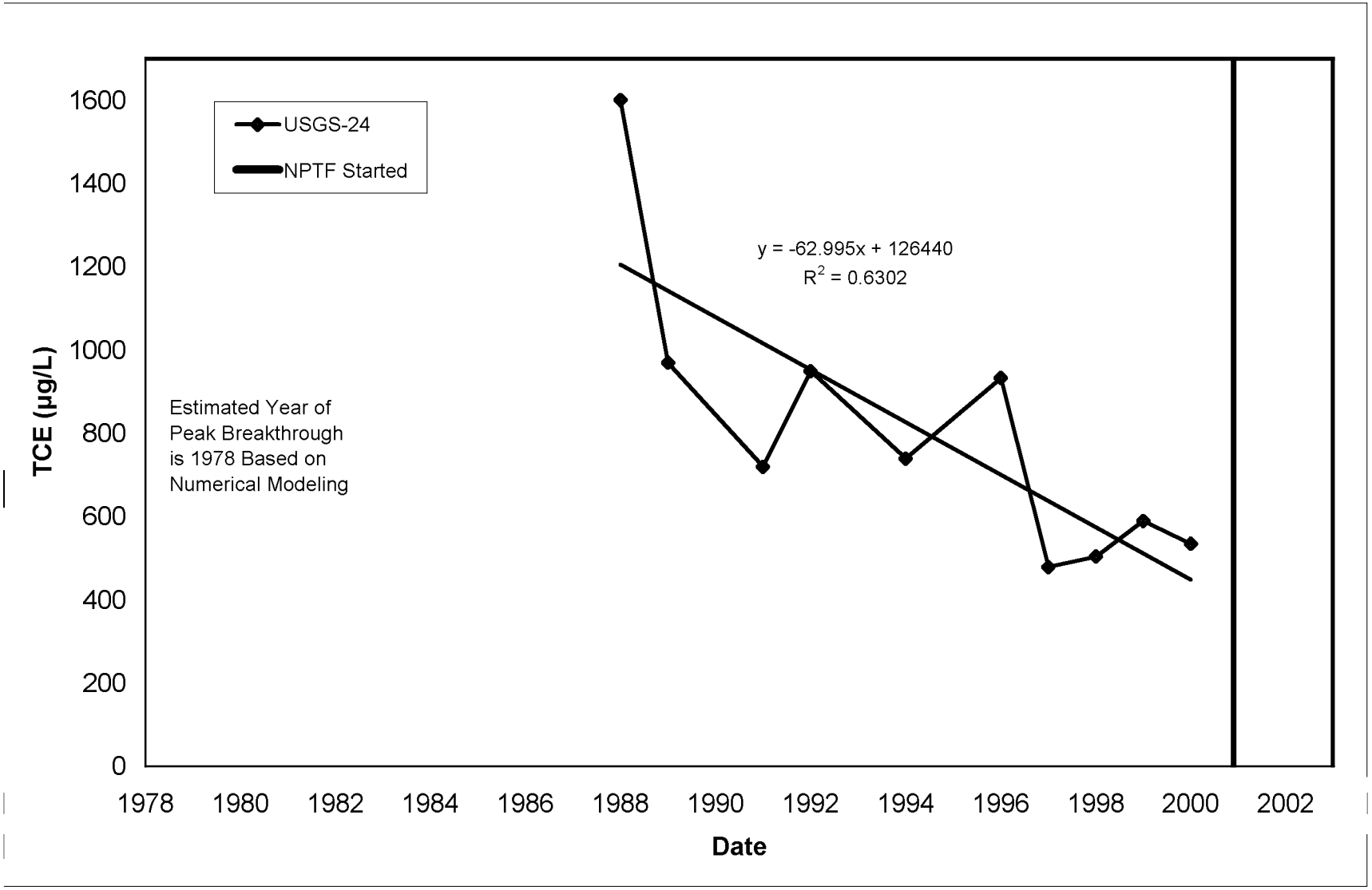

Figure 7-3. Linear regression fit to annual averages for USGS-24 indicates statistically significant negative trend.

gradual reductions in concentration over long time periods. Because of this, analysis of data from wells hrther downgradient may be more difficult. The use of more robust techniques such as hypothesis testing using the Mann-Kendall statistic (as recommended by EPA [1999], DOE [1999], and others) may be required to verify the presence or absence of meaninghl trends.

It is also evident from this exercise that substantial variability can be observed in the contaminant concentration data. Because of this variability, data covering long periods of time may be required to reliably identify trends. For example, if only the last 5 years of USGS-24 data had been available for analysis, the process described above would not have identified a meaninghl trend. Groundwater samples will need to be consistently collected and analyzed over long time periods to adequately evaluate MNA performance trends.

7.2.3 Evaluation of the Rate of Trichloroethene Degradation

In this section, available data up through 2002 are analyzed to determine the rate that TCE and cis-DCE are degrading in the Operable Unit (OU) 1-07B groundwater plume. Because the concentrations of tritium are rapidly declining through natural radioactive decay (tritium has a 12-year half-life), the tritium data collected during MNA operations will become increasingly less reliable for calculation of the TCE degradation rate. For this reason, the available data are used here to calculate a best estimate of the degradation rate. It is not anticipated that the degradation rate can be recalculated reliably in hture years, due to the natural decay of tritium.

7.2.3.1 Tracer Corrected Method of Estimating Trichloroethene Degradation Rate.

Researchers have evaluated several first-order rate estimation methods to account for attenuation observed in field data (Sorenson et al. 2000). Independent means of quantifying transformation rates are preferred because dispersion and plume instability can confound accurate estimation of degradation constants from spatially trended concentration data. As developed in Sorenson et al. (2000) and discussed in Peterson et al. (2000), tritium can be used as an effective tracer to estimate a first-order degradation rate constant for TCE at this site.

Tritium was disposed with TCE at the TSF-05 injection well. This radionuclide is conservative in the environment and, with the exception of radioactive decay, remains largely unaltered by geochemical and biological processes. Because the tritium tracer is subject to the same geohydrological transport mechanisms as TCE, it can be reasonably assumed that the ratio of concentrations of TCE to tritium (when corrected for radioactive decay) will be constant throughout the plume in the absence of TCE degradation. If, however, the ratio of the contaminant to the tracer decreases with distance from the source, then a first-order degradation rate for TCE can be readily estimated.

It has been demonstrated at TAN that the ratio of TCE to tracer decreases with distance downgradient from the TSF-05 injection well. As developed in Sorenson et al. (2000), changes in contaminant to tracer ratios can be directly related to degradation rates. When the natural logarithm of the ratio of contaminant concentration to tracer concentration is plotted against distance along a flow path, the slope of the line is equal to the first-order degradation rate divided by the groundwater velocity, as follows:

$$\ln(C^*_x) = (\lambda / v_x)x + \ln(C^*_A) \quad (1)$$

where

C^*_x = ratio of contaminant concentration to tracer concentration (decay-corrected tritium) at point x

λ = TCE degradation rate

v_x = groundwater velocity

C^*_A = ratio of contaminant concentration to tracer concentration (decay-corrected tritium) at an upgradient reference point.

The tracer-corrected method can be applied to available water-chemistry data to estimate the degradation rate constant for TCE in groundwater at TAN. The TCE and tritium data sets are discussed in the following section.

7.2.3.2 Data Available for Calculation of the Degradation Rate Constant. Trichloroethene and tritium concentration data are available from 10 wells located near the axis of the plume at TAN. Many of the wells have been monitored since the early 1990s up through 2002. Results are available from 98 independent samples taken from these wells. These results comprise an extensive set of TCE and tritium data.

Two types of data collected from wells near the plume axis at TAN could not be used. First, the 1990 sludge removal activity at TSF-05 may have disproportionately reduced the source of the tritium. Because this removal action may have artificially caused changes in the contaminant to tracer ratios near TSF-05, the data between wells TSF-05 and TAN-39 could not be used for the tracer-corrected approach (Sorenson et al. 2000). Secondly, the reinjection of treated water from the NPTF has begun to affect contaminant concentrations in nearby wells TAN-33, -38, -39, -48, and USGS-24. Contaminant and tracer data from these wells after October 2001 (start of full-scale NPTF operations) are unreliable for purposes of this method and have been excluded from the data set.

Groundwater velocity is a critical parameter in the degradation rate calculation. Using tritium data from five wells along the plume axis and correcting for radioactive decay, Sorenson et al. (2000) estimated average groundwater velocity to be 0.11 m/day (0.35 ft/day). Because transverse dispersion may in fact slow longitudinal transport, resulting in an underestimate of groundwater velocity as measured in these five axial wells, this value represents a lower bounding value of the groundwater velocity[b]. Use of this bounding groundwater velocity value will underestimate the rate of degradation, and hence is conservative as used in the degradation rate calculation. Measured tritium concentrations were corrected for radioactive decay by estimating total travel time of the groundwater from TAN-39 to the measurement point, assuming a velocity of 0.35 ft/day.

7.2.3.3 Calculation of the Degradation Rate Constant. The ratio of TCE to tritium concentrations (corrected for radioactive decay) at varying distances from the injection point is plotted on Figure 7-4. In this figure, results were compiled for 10 wells that are located downgradient of TAN-39 near the axis of the plume. The data used in this figure were collected during 1988-2002, demonstrating that the analysis is both temporally and spatially consistent.

As illustrated in Figure 7-4, the data indicate correlation between TCE concentrations and distance from the injection point. Because the data are expressed in relation to a conservative tracer, the observed decline in concentration is an effective measure of true degradation, independent of dispersion or other geohydrologic processes. Although some variance is observed in the data, a first-order regression fits well. The dashed lines in the figure indicate upper and lower bounds of the 95% confidence interval around the mean slope. As observed by Sorenson et al. (2000), the range defined by this confidence interval is small considering the potential complexity of the problem.

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b. A numerical flow model calibrated to tritium data predicts an average velocity of 0.15 m/day (0.49 ft/day), which is greater than that used in the rate calculation (Sorenson et al. 2000).

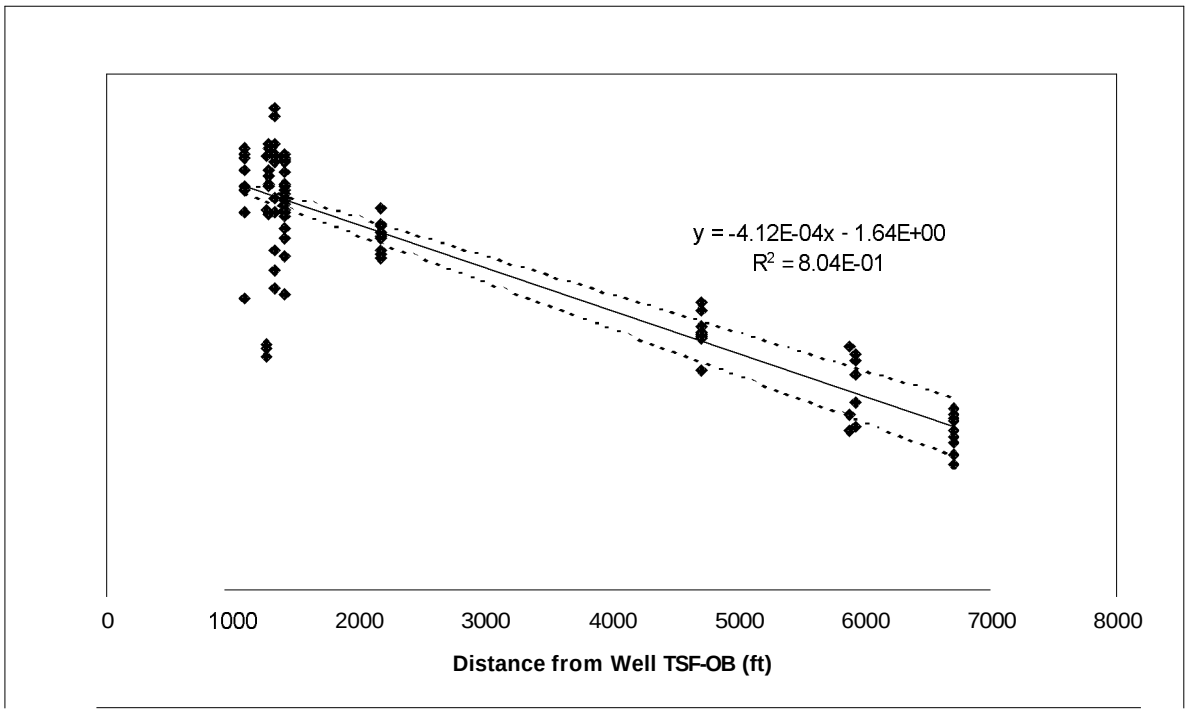

Figure 7-4. First-order degradation rate estimation using tracer-corrected trichloroethene concentrations.

As discussed previously, the TCE degradation rate is estimated by multiplying the slope of the regression by groundwater velocity. The range of half-life values resulting from the regression analysis, assuming a 0.11 m/day (0.35 ft/day) average groundwater velocity, is presented in Table 7-1.

Table 7-1. Trichloroethene half-life. as derived from conservative tracer data.

	Half-Life (in years)	Upper 95%	Lower 95%
TCE/Tritium	13.2	14.6	12.0

Neither TCE nor tritium are sorbed (absorption or adsorption) in the fractured basalt aquifer beneath TAN (Ingram et al. 1998). Tritium is clearly a conservative tracer and can be used with the tracer-corrected method to estimate the degradation rate of TCE independent of dispersion. For purposes of monitoring remedy performance, a conservative estimate of TCE half-life is best estimated by using tritium data combined with a bounding lower estimate for groundwater velocity, as described above. Thus, a half-life for TCE of 13.2 years will be used for hture modeling and evaluation of TCE concentration trends. This half-life is consistent with that calculated several years ago with a smaller data set (Sorenson et al. 2000).

The degradation rate half-life was also evaluated using ratios of TCE concentrations to PCE concentrations, as suggested by Sorenson et al. (2000). Although PCE is subject to minor volatilization and sorption, it is resistant to biodegradation processes under the aerobic conditions that exist in the portion of the plume considered and is relatively conservative compared to TCE. Because of potential attenuation processes affecting PCE, the degradation rate estimated using PCE as a tracer is less accurate than that calculated using tritium as a tracer. It is expected that the degradation half-life estimated from the TCE/PCE data set will be longer than that estimated from the TCE/tritium data set because PCE is less conservative than tritium. The TCE half-life estimate using PCE data was 23.6 years (with lower and upper 95% confidence limits of 22.0 and 25.4 years). Analysis of the TCE/PCE data set, which was even

larger than the TCE/tritium data set, provided additional confidence in the tracer-corrected method, and was consistent with expected fate and transport properties of the solutes.

7.2.4 Evaluation of Rate of cis-DCE Degradation Using Tritium Tracer

Degradation constants and half-lives were also estimated for cis-DCE using tritium as a tracer in the tracer-corrected method described in the previous section. The range of half-life values, assuming a 0.11 m/day (0.35 ft/day) average groundwater velocity, is presented in Table 7-2. The ratio of cis-DCE to tritium concentrations (corrected for radioactive decay) at varying distances from the injection point is plotted in Figure 7-5. The best estimate for a cis-DCE half-life is 8.4 years. This is consistent with the fact that cis-DCE is more easily oxidized than TCE (Vogel et al. 1987), and would therefore be expected to degrade more quickly under aerobic conditions. Again, this adds confidence regarding the applicability of the method at TAN.

Table 7-2. cis-DCE half-life. as derived from conservative tracer data.

	Half-life (in years)	Upper 95%	Lower 95%
cis-DCE/Tritium	8.4	9.3	7.7

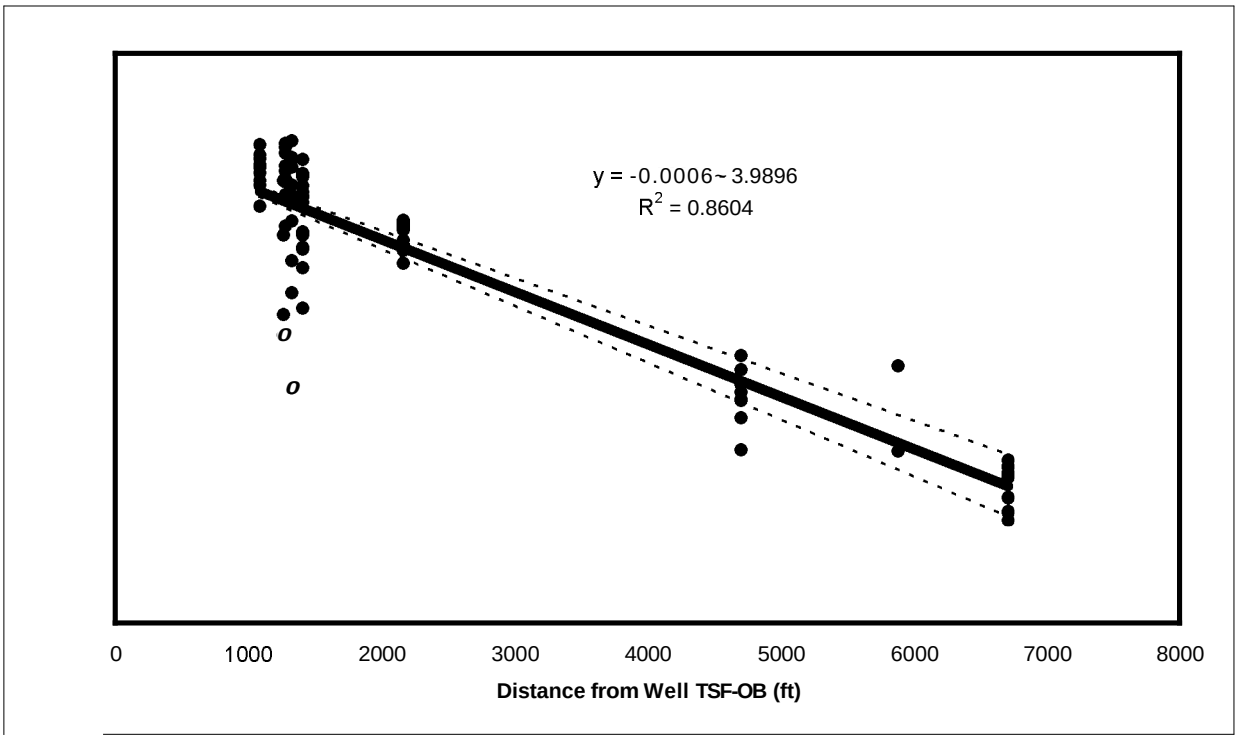

Figure 7-5. First-order degradation rate estimation using tracer-corrected cis-DCE concentrations.

The degradation rate estimate for cis-DCE also was examined using PCE as a tracer. It is expected that the degradation half-life estimated from the cis-DCE/PCE data set will be longer than that estimated from the cis-DCE/tritium data set because PCE is less conservative than tritium and some sorption of PCE may occur. The cis-DCE half-life estimate, using PCE data, was 12.4 years (with lower and upper 95% confidence limits of 11.5 and 13.5 years). Analysis of cis-DCE/tritium and cis-DCE/PCE data

sets validates the tracer-corrected method and shows degradation of cis-DCE in concert with TCE degradation.

7.2.5 Vertical Profiling Data

During Fiscal Year (FY) 2002, vertically discrete samples were collected from four MNA wells that have been fitted with multiport FLUTe™ liners. A detailed discussion of the deployment, sampling, and performance of the FLUTe™ liners is available in Wymore et. al 2003[c]. Figure 7-6 presents the TCE and tritium data for the MNA FLUTe™ wells TAN-51, -52, -54, and -55. From Figure 7-6, it is apparent that TCE concentrations varied substantially with depth in TAN-51 and TAN-55. Furthermore, the TCE concentration profiles are inconsistent between wells. Vertically discrete samples from TAN-51 had higher concentrations in the upper and lower intervals, while TAN-55 had higher concentrations in the middle intervals. The TCE profiles for TAN-52 and TAN-54 were more constant with depth, although some variation was still detected. As shown in Figure 7-6, the tritium profiles were remarkably similar to the TCE profiles for each well. Similar profiles also were detected for several other analytes in the FLUTe™ wells (Wymore et. al 2003[c]). This demonstrates the overall consistency of the FLUTe™ data. The well-to-well variability demonstrates that vertical concentration profiles are a function of local stratigraphy, as opposed to large-scale preferential flow.

Besides variability in TCE concentration with depth, it was also of interest to see whether there is indication that degradation rates vary with depth within the aquifer. Figure 7-6 also presents the TCE/tritium ratios for the four MNA FLUTe™ wells. It should be noted that this plot was created using the raw tritium data and not the corrected tritium data that was used for calculation of the degradation half-lives. The reason for this is that TAN-54 and TAN-55 are off-axis wells, and any travel times calculated from TSF-05 would be tenuous at best. Thus, the magnitude of the ratios is not as important as the trend in the ratio for a given well. Figure 7-6 shows that the TCE/tritium ratios were generally constant for all of the wells. The most obvious exception is a sample collected from TAN-55 at the 221-ft depth, which had TCE/tritium ratios roughly 2 to 2.5 times higher than the rest of the TAN-55 profile. The reason for this is that tritium for this sample was reported as less than the minimum detectable activity (MDA), so calculation of the ratio is misleading. All TCE/tritium ratios that used tritium values reported as less than their respective MDAs are represented by red squares in Figure 7-6. If these points are not considered, then the TCE/tritium ratios are relatively constant in each well. Thus, the degradation rate calculated using data from these wells is independent of the depth of the sample. This point is hrther supported by the fact that the 2002 TAN-51 and TAN-52 FLUTe™ data were included in the TCE degradation rate estimate, which, as discussed in Section 7.3.3, resulted in a relatively narrow 95% confidence interval about the regression line.

7.2.6 Trichloroethene Plume Boundaries

The 1997 OU 1-07B Explanation of Significant Differences (ESD) (INEEL 1997b) presented the size and shape of the TCE plume in the form of a TCE isopleth map. The map was hand-contoured using all data available during publication of the ESD. The plume, as defined by the 5-µg/L TCE isopleth, extended south and east to include wells GIN-02 and ANP-08 in 1997. Wells MW-2 and TAN-24A fell outside the 5-µg/L isopleth at that time.

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c. Wymore, R. A., K. Harris, and K. S. Sorenson, Jr., 2003, "Final Quick Win Vertical Profile Sampling Report (Draft)," NW-ID-2003-046, North Wind, Inc., Idaho Falls, Idaho, September 2003.

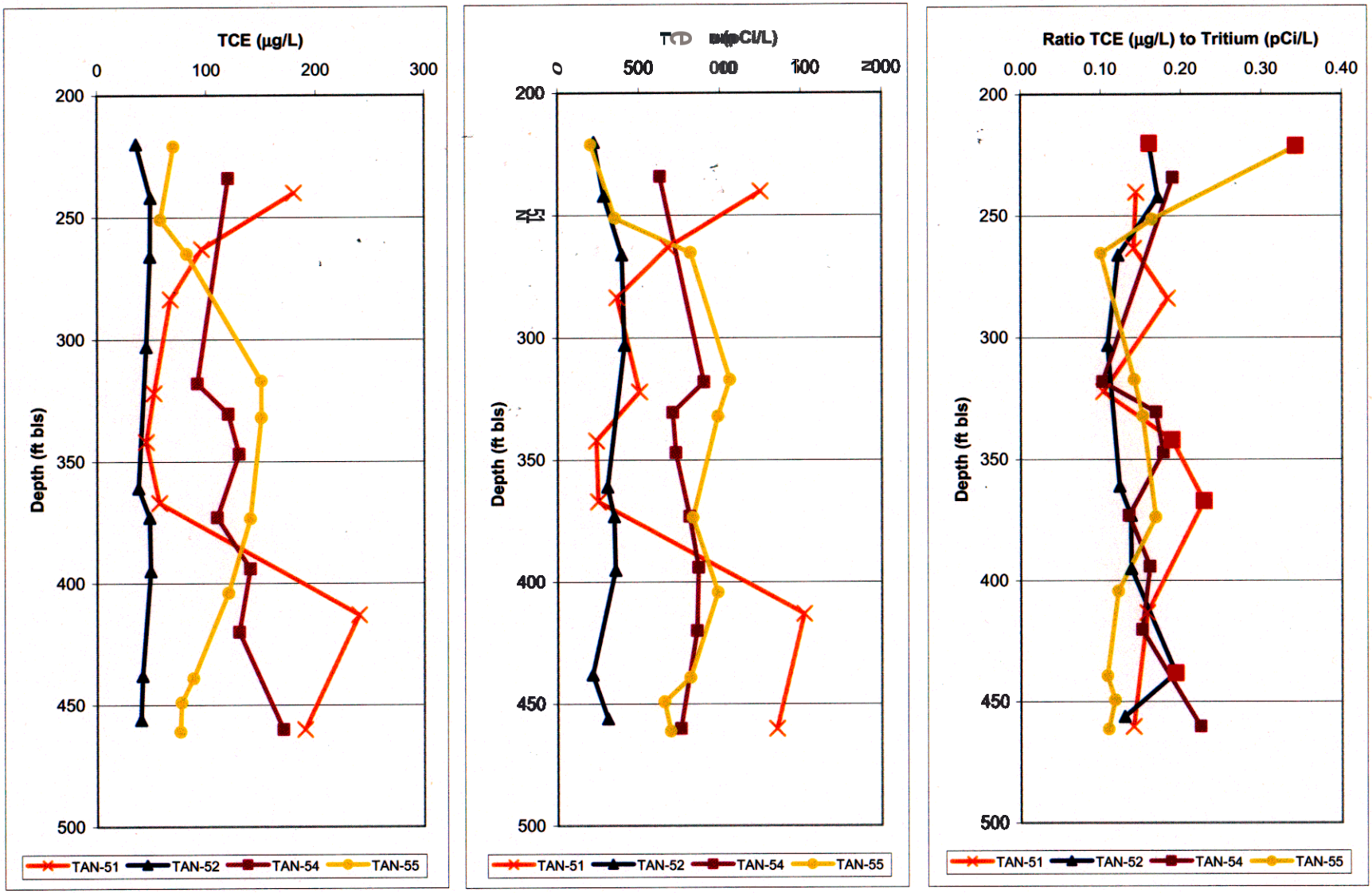

Figure 7-6. Vertical distribution of trichloroethene concentrations in 2002.

Data collected since 1997 indicated that the size and shape of the 5-µg/L isopleth have been relatively stable. Data collected in June 2002 indicate that MW-2 and TAN-24A are still outside the plume (i.e., TCE concentrations below 5 µg/L). In addition, the most recent sample collected at GIN-2 (October 15, 2002) was also below 5 µg/L TCE. Most recent TCE concentrations at ANP-08 (16.4 µg/L in April of 2003, results made available prior to the publication of this report) are higher than the previous TEC concentrations (12.58 µg/L in August of 2000 and 11 µg/L in September 1996).

Three other wells located near the edge of the distal portion of the TCE plume exhibit similar TCE concentrations and positions relative to the 5-µg/L isopleth, as they did during the construction of the 1997 contour map. Trichloroethene concentrations at TAN-21 were measured at 9 µg/L in October 1997, and 7 µg/L in July 2002. Trichloroethene concentrations at TAN-6 were less than 5 µg/L in both 1997 and 2002. TAN-15 yielded TCE concentrations of 44 µg/L and 40 µg/L in 1997 and 2002, respectively. The similarity of TCE concentrations in wells near the plume edge in 1997 and 2002 suggests that the overall size of the plume was nearly stable over the 5-year observation period. Aside from the analytical uncertainties involved in the sampling and analysis of TCE, hand contouring produces some uncertainty in the geometry of the plume because different analysts may produce slightly different representations of TCE spatial distribution. However, the distance between monitoring wells located near the plume's edges limits the uncertainty in plume size estimates. At the current leading edge of the plume, several wells are spaced approximately 500 to 1,000 ft apart; therefore, the overall uncertainty in the estimate of the location of the leading edge of the plume cannot exceed 1,000 ft and is probably less than half that distance.

7.2.7 Numerical Model Verification and Update Work

During Fiscal Year 2002, the MNA groundwater flow and transport model, which was originally developed using TETRAD, was converted to a MODFLOW/MT3DMS format (Martian 2002). While the TETRAD-based model allowed simulation of a wide range of physical processes, including DNAPL TCE dissolution, the software is highly specialized and requires a large amount of experience to use. The MODFLOW/MT3DMS-based model allows a larger group of scientists/engineers to use the numerical TAN model for remediation hypothesis testing. A complete discussion of the original TETRAD model can be found in *Numerical Modeling Support of the Natural Attenuation Field Evaluation for Trichloroethene at the Test Area North, Operable Unit 1-07B* (Martian 1999). Much of the following discussion is summarized from both documents (Martian 1999 and 2002).

The Department of Defense Groundwater Modeling System (GMS) software is a graphical user interface for developing numerical groundwater models. The software supports several simulation codes, including MODFLOW and MT3DMS, and allows the user to run and transfer information between the different codes. The GMS software provides tools for grid generation, geostatistics, and visualizing simulation results.

The MODFLOW software (McDonald and Harbaugh 1988) is a modular, finite-difference groundwater flow model. The software has been in existence since 1983 and has become the most widely used code for simulating groundwater flow. The modular structure of MODFLOW consists of the main program and a series of independent subroutines. Each subroutine simulates a specific hydrologic feature such as wells, surface recharge, and river-aquifer interaction.

MT3DMS (Zheng and Wang 1999) is a solute transport model for MODFLOW. MT3DMS uses a steady-state or transient velocity field provided by MODFLOW during computation of contaminant transport. MT3DMS can simulate anisotropic dispersion, first-order contaminant decay and production, and linear or nonlinear sorption for multiple species.

In 2002, the TETRAD model was transferred into the GMS/MODFLOW/MT3DMS software. The sections below summarize important details of the conversion process.

7.2.7.1 MODFLOW/MT3DMS Model Domain. The original TETRAD model consisted of a larger, regional-scale model with several refined areas. The domain for the MODFLOW/MT3DMS model was established based on the area of predicted TCE travel in the TETRAD model. The MODFLOW/MT3DMS regional model encompassed the same area as the first level of refinement in the TETRAD domain. The MODFLOW/MT3DMS model used the same horizontal and vertical refinement as the TETRAD model, but the refinement was carried out to the model boundaries.

The MODFLOW/MT3DMS regional model served as the source of boundary conditions for a submodel, which contains the current TCE plume and was used for model calibration to the existing TCE and tritium plumes. Because the submodel is the only portion of the MODFLOW/MT3DMS model that is calibrated for transport, all numerical simulations of tritium and TCE concentrations that have been reported for the MODFLOW/MT3DMS model are derived from this portion of the domain.

Parameterization of the model domain was completed through the use of several computer programs that were written in the PVWAVE programming language (Visual Numerics 2001). The programs converted TETRAD parameterization information for most MODFLOW/MT3DMS grid blocks to GMS ASCII data files, which are compatible with the MODFLOW/MT3DMS model. In some cases, this required refinement to match the TETRAD and MODFLOW/MT3DMS grids. In other cases, no refinement was required. Due to the slight differences between the grid block sizes of the TETRAD and MODFLOW/MT3DMS models, some parameterization of the MODFLOW model was required inside the GMS environment. If hrther parameterization of the MODLFLOW flow model is required, users are advised to read Martian (2002) and its appendices prior to commencement of that effort.

7.2.7.2 MODFLOW Flow Model Conversion. The MODFLOW simulation consisted of 98 stress periods representing the years 1955 through 2018. During this period, production/injection well flow rates and disposal pond recharge data are specified in annual or monthly periods depending on the historical water-use records used to create the TETRAD simulations.

The TETRAD model required input of the intrinsic permeability, and internally calculated the hydraulic conductivity from the state of the water. The MODFLOW model required input of hydraulic conductivity, which can be calculated from the intrinsic permeability by the following equation:

$$K = \frac{k\rho g}{\mu} \tag{2}$$

where

k = permeability

ρ = water density

g = gravitational constant

μ = dynamic viscosity.

The hydraulic conductivity input files, used in the MODFLOW model, were generated by converting the intrinsic permeability data set used in the TETRAD model into hydraulic conductivity values using Equation 2. These values were adjusted to the assumed groundwater viscosity and density at a groundwater temperature of 15.56°C (60°F).

The MODFLOW simulation duplicated the flow field seen in the TETRAD simulation and that observed at the TAN site. The water table at the TAN site is relatively flat (1 ft/mi gradient) and has a southeasterly direction with a stronger easterly gradient near the Technical Support Facility (TSF).

7.2.7.3 MT3DMS Transport Model Calibration. The TETRAD modeling used tritium, total radiation, and water volume disposal records for the TSF-05 disposal well from 1961 to 1972 to construct the tritium source term. The tritium source term and aquifer concentration records were used to calibrate the TETRAD model's porosity and dispersivity. The calibrated fracture porosity was determined to be 3.5%, and the calibrated dispersivity was zero in both the longitudinal and transverse directions. Typically during transport calibration, the model dispersivity is increased until the simulated amount of spreading matches the calibration data. However, in the TAN TETRAD model, numerical dispersion alone created the appropriate amount of dispersion to provide a good match between observed and simulated tritium concentrations.

The TETRAD modeling used the aquifer velocity field obtained from the tritium calibration as the basis for TCE calibration. The TCE source term was varied for a degrading and a nondegrading TCE scenario to match the historical TCE concentrations. An 11-year half-life was chosen for the degrading TCE case because of similarities in the behavior of the TCE and tritium plumes. In order to match the TCE concentrations, it was necessary to separate the TCE source into initial and residual components, and different initial and residual source terms were calibrated for a degrading and nondegrading TCE plume. The initial source term was simply scaled from the tritium source term and the magnitude was changed for the degrading and nondegrading calibration. The TETRAD-calibrated degrading source terms were 1,100 gal of TCE in the initial source and a 0.0026 gal/day residual rate. The nondegrading TCE calibration required reducing the initial source to 66 gal of TCE and increasing the residual source to 0.012 gal/day.

The TETRAD tritium, degrading TCE, and nondegrading TCE simulations were combined into a single three-solute species MT3DMS simulation. The MT3DMS simulations required specification of additional dispersivity to match the tritium and TCE plume-spreading seen in the TETRAD simulations. A 2-m longitudinal and transverse dispersivity provided the best match between the two models. Dispersivity values larger than 2 m were evaluated in the MT3D simulations to match the dispersive behavior near TSF. However, these values provided poor agreement with wells downgradient of the TSF. The 2-m value provided the best overall agreement with the TETRAD simulations, although there remained some differences in the modeled TCE distributions between TETRAD and MODFLOW/MT3DMS. This lack of agreement is attributed primarily to differences in numerical dispersion in the two models.

7.2.7.4 Tritium Simulation Results. Only very limited sampling was done in the aquifer wells at TAN prior to the Remedial Investigation/Feasibility Study (RI/FS) in 1992. Well USGS-24 is the one exception, and it was sampled for tritium in 1965, 1977, and during the 1980s. The high tritium concentration observed in 1977 is largely the basis for TETRAD-calibrated porosity. Both TETRAD and MT3DMS slightly overpredicted peak concentration, and MT3DMS predicted values slightly higher than TETRAD. However, MT3DMS matched the concentrations after 1992 better than TETRAD, and the overall match with observed values is comparable to TETRAD. At the other wells, the TETRAD and MT3D simulations are comparable and either TETRAD or MT3DMS can have slightly better or worse agreement with the observed data.

7.2.7.5 Potential Updates to the MNA Numerical Simulator. As discussed previously, degrading TCE simulations were performed assuming an 11-year TCE half-life. Analysis of current data yields a best estimate of the TCE degradation half-life that is slightly longer and has associated uncertainty that needs to be reflected in the predictive simulations (see Section 7.2.3). In addition, it is

anticipated that bounding estimate scenarios will need to be generated to describe the latest year of peak breakthrough that will still allow for attainment of groundwater remedial action objectives (RAOs) by 2095. The generation of both best estimates and bounding estimates of year of peak breakthrough will simplify the hture evaluation of MNA performance and addresses the need to incorporate uncertainty in the model predictions. The model updates that will be required to support hture MNA evaluations will be discussed in the MNA Operations, Monitoring, and Maintenance (OM&M) Plan (DOE-ID 2003b).

7.3 Analysis of Radionuclide Data

This section describes the concentrations of radionuclides observed up through 2002 in distal zone monitoring wells and discusses evidence of rapid attenuation of radionuclides observed in the medial zone monitoring wells. Radiological COCs for the MNA remedy include strontium-90, cesium-137, uranium-234, and tritium.

7.3.1 Radionuclide Concentrations in the Distal Zone

Radionuclide data for strontium-90, cesium-137, and uranium-234 in the distal zone MNA wells were not collected in 2002, as past sampling indicated that there were no detectable concentrations this far from TSF-05. Because tritium has been consistently detected in the distal zone, additional sampling and analysis for this analyte were recently completed.

The distal zone wells TAN-16 and TAN-21 were sampled for tritium in 2002; ANP-8 was sampled last in 2003. The sample results indicated that tritium concentrations at these locations were below the MDA. Utilizing FLUTe™ liners, vertically discrete samples also were collected from wells TAN-51, -54, -55, and -52, all located in the distal zone. Figure 7-6 presents results of these samples as a vertical distribution of 2002 tritium concentrations in the wells. Although the levels were higher in these wells, all reported tritium concentrations were well below the MCL. These new data indicate that tritium concentrations in the distal portion of the plume are below MCLs.

7.3.2 Concentrations in the Hotspot and Medial Zone

The ROD Amendment (DOE-ID 2001) includes the assumption that radionuclides will attenuate naturally through processes of sorption and radioactive decay to meet cleanup objectives throughout the plume. Therefore, radionuclide concentrations have been monitored in selected wells near TSF-05 to verify this assumption. Radionuclide data collected up through 2002 are described in this section to provide a point of comparison for hture monitoring. A selected number of wells anticipated to be used for hture MNA monitoring are included in this discussion. These data indicate that the natural processes already are having a measurable effect on radionuclide concentrations at some locations.

Tritium concentrations for all wells are presently below the MCL. Concentration plots are shown in Figures 7-7 through 7-9. TSF-05B and TAN-25 (Figure 7-7) showed marked concentration decreases until the start of lactate injections in TSF-05, which is thought to have influenced the release of tritium from the secondary source sludge causing concentration trends to level off. Tritium concentrations at TAN-37A and -28 (Figures 7-8) show fluctuations in concentrations within a constant range, whereas TAN-30A and -29 (Figures 7-9) show decreasing concentrations following the start of lactate injections.

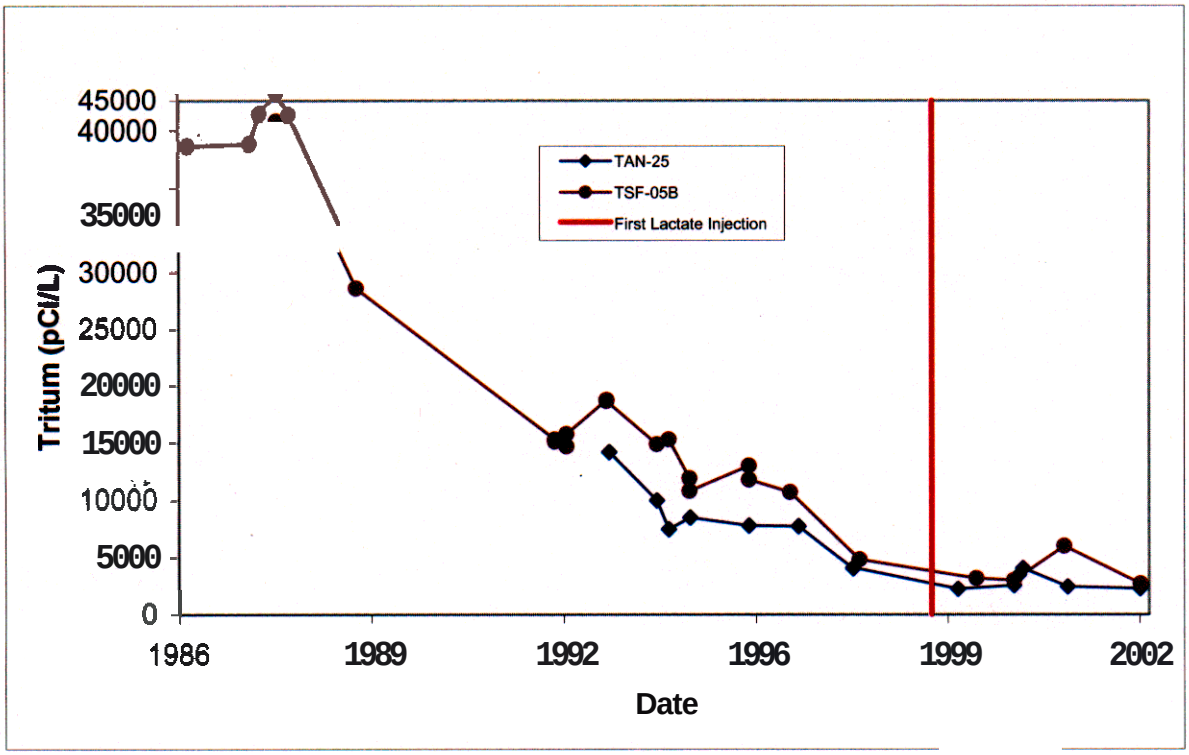

Figure 7-7. Tritium concentrations in TSF-OSB and TAN-25.

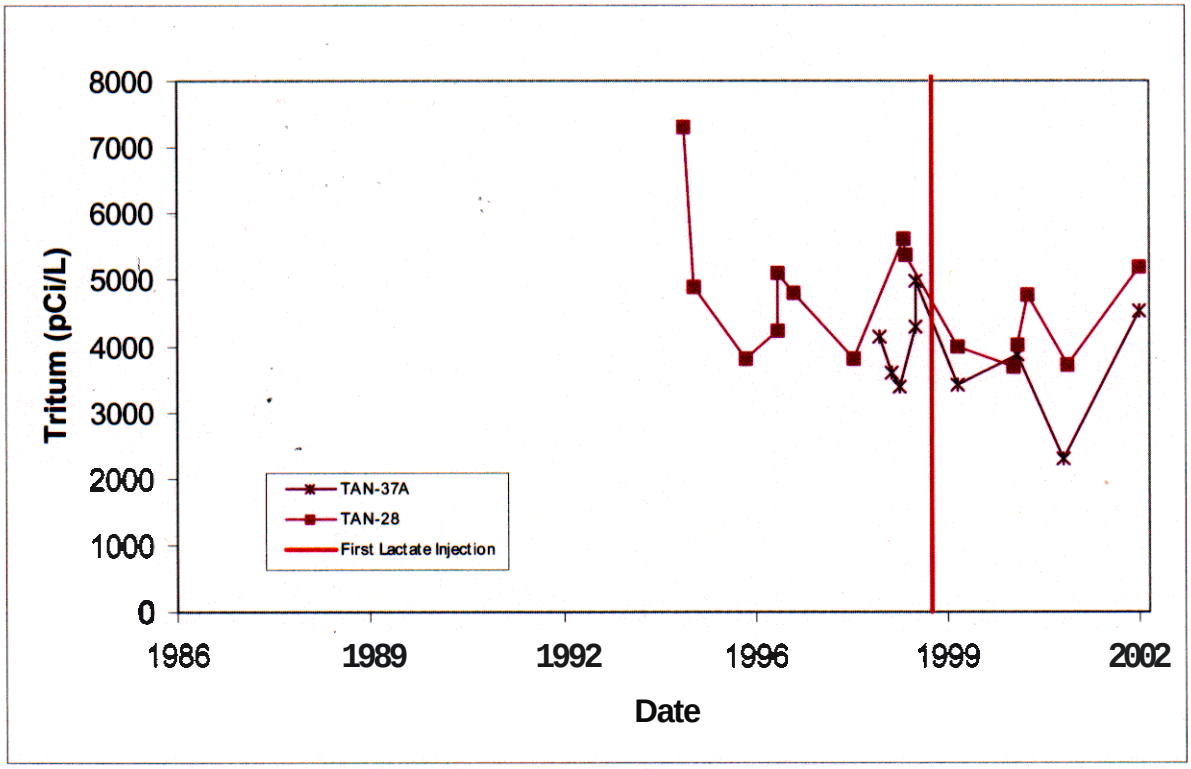

Figure 7-8. Tritium concentrations in TAN-37A and TAN-28.

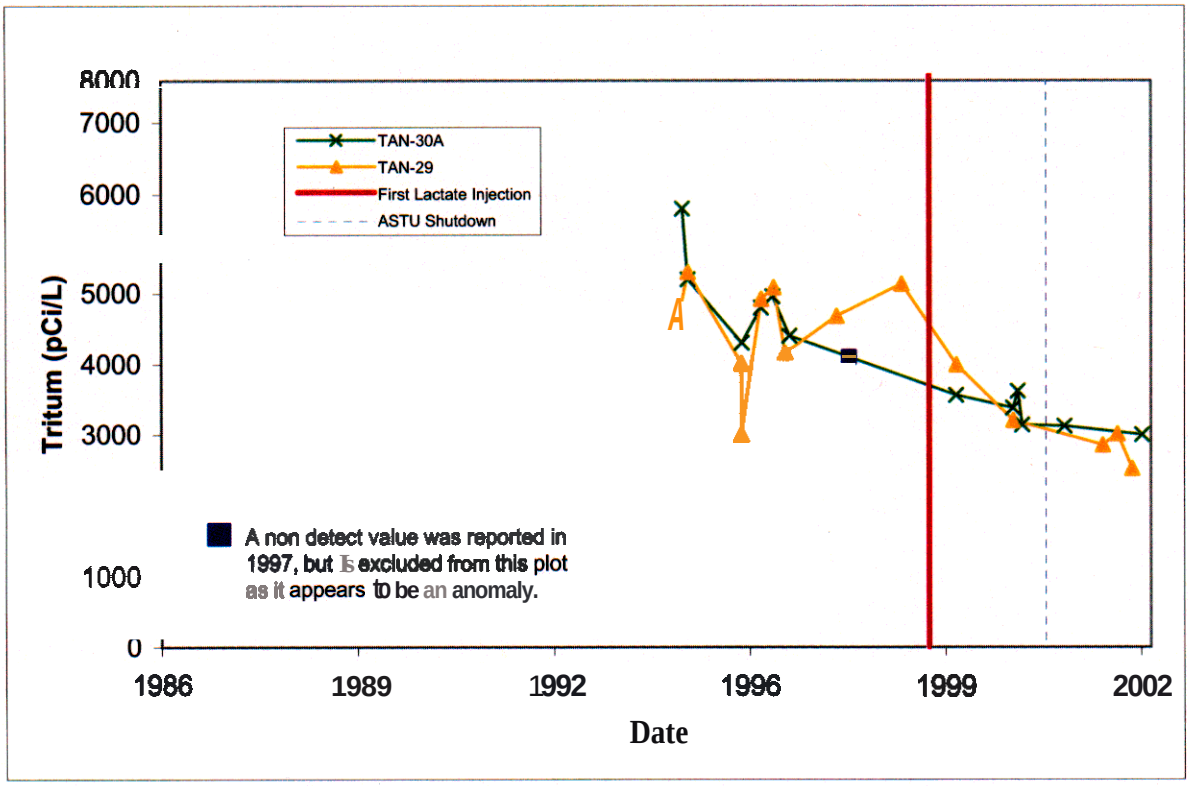

Figure 7-9. Tritium concentrations in TAN-30A and TAN-29.

Plots of strontium-90 data are shown in Figures 7-10 through 7-12. All of the wells within a distance of 150 m from TSF-05 show concentrations above the 8-pCi/L MCL except for recent data reported for TAN-30A. Increases in strontium-90 concentrations at TSF-05B, TAN-25, -37A, and -28 may be attributable to the mobilization of strontium-90 from the secondary source sludge or to desorption from the formation as a result of organic acid production following lactate injections. Cesium-137 is also detected in TSF-05B and TAN-25. Figure 7-13 plots the historical cesium-137 data and, as with the strontium-90 data, indicates some influence from in situ bioremediation (ISB) operations. Cesium-137 concentrations at all other locations were consistently below the MDA. Under the Phase C Groundwater Monitoring Plan (INEEL 2002a), cesium-137 data were collected until 1999. Cesium-137 data collected after 1999 are reported in the ISB Annual Reports.

The recent variability in tritium and strontium-90 concentrations near TSF-05 is consistent with the current understanding of the ISB treatment process. The injection of lactate may result in localized mobilization of radionuclides due to the hydraulics of the injection process as well as geochemical changes that may reduce sorption. This analysis supports the conclusion that natural processes are rapidly attenuating concentrations of radionuclide contaminants throughout the plume, which is further demonstrated below.

To further evaluate the assumption that processes other than radioactive decay are reducing concentrations of certain radionuclides, strontium-90 data collected during 2000, 2001 and 2002 are analyzed in relation to distance along the plume axis. If radioactive decay were the only process that affected strontium-90, then concentrations, when plotted as the natural log of the concentration ratio vs. distance along the flow path, would decline with a slope that corresponds to the rate of radioactive decay. If processes in addition to decay are reducing the concentrations, then the concentration vs. distance plot will be steeper and have a greater apparent decay coefficient.

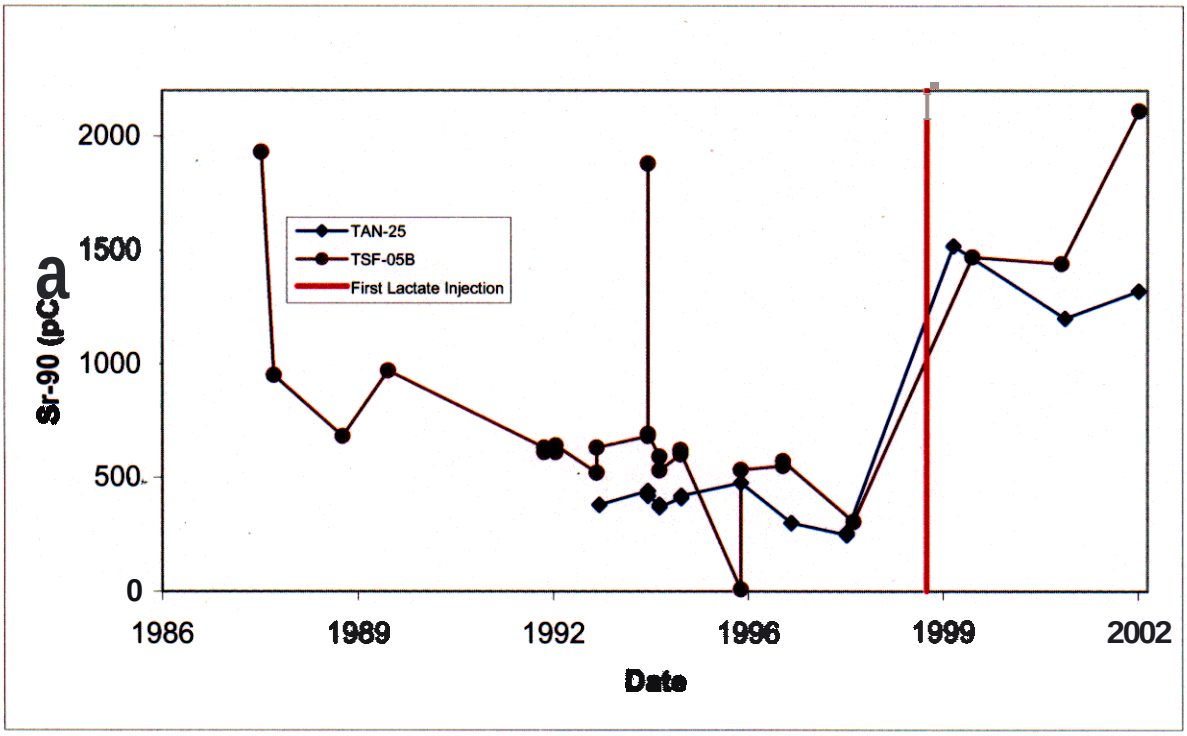

Figure 7-10. Strontium-90 concentrations in TSF-OSB and TAN-25.

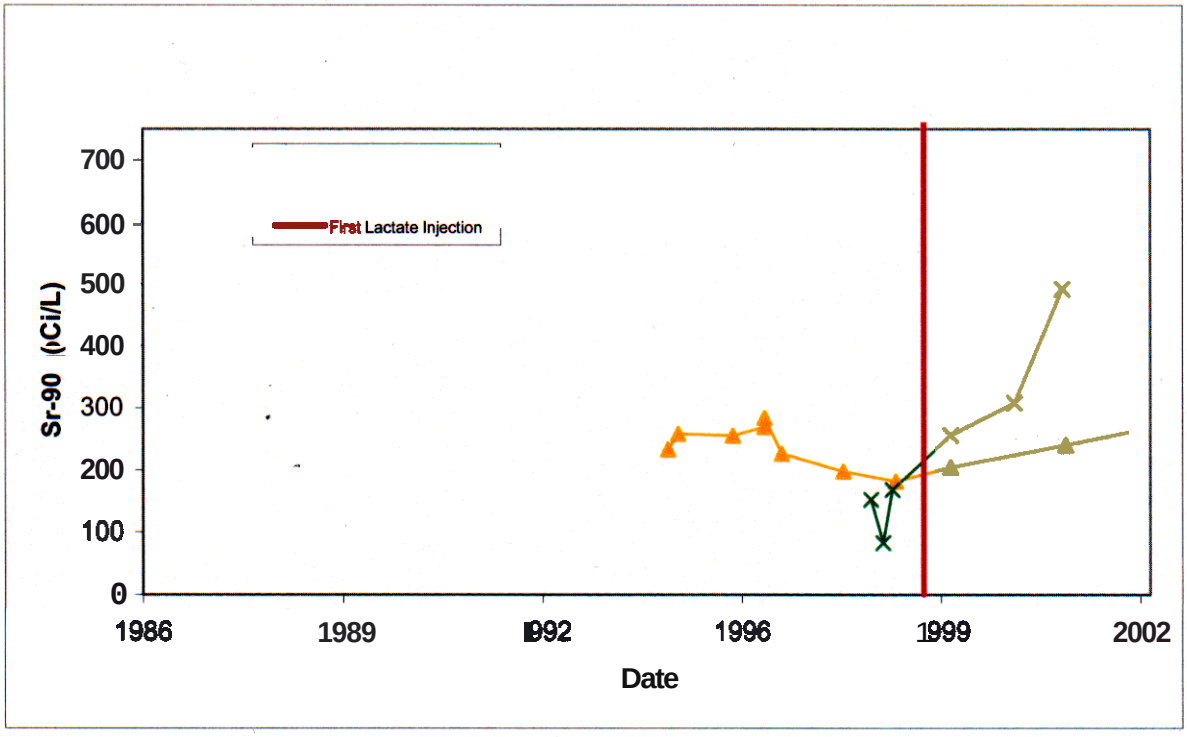

Figure 7-11. Strontium-90 concentrations in TAN-28 and -37A.

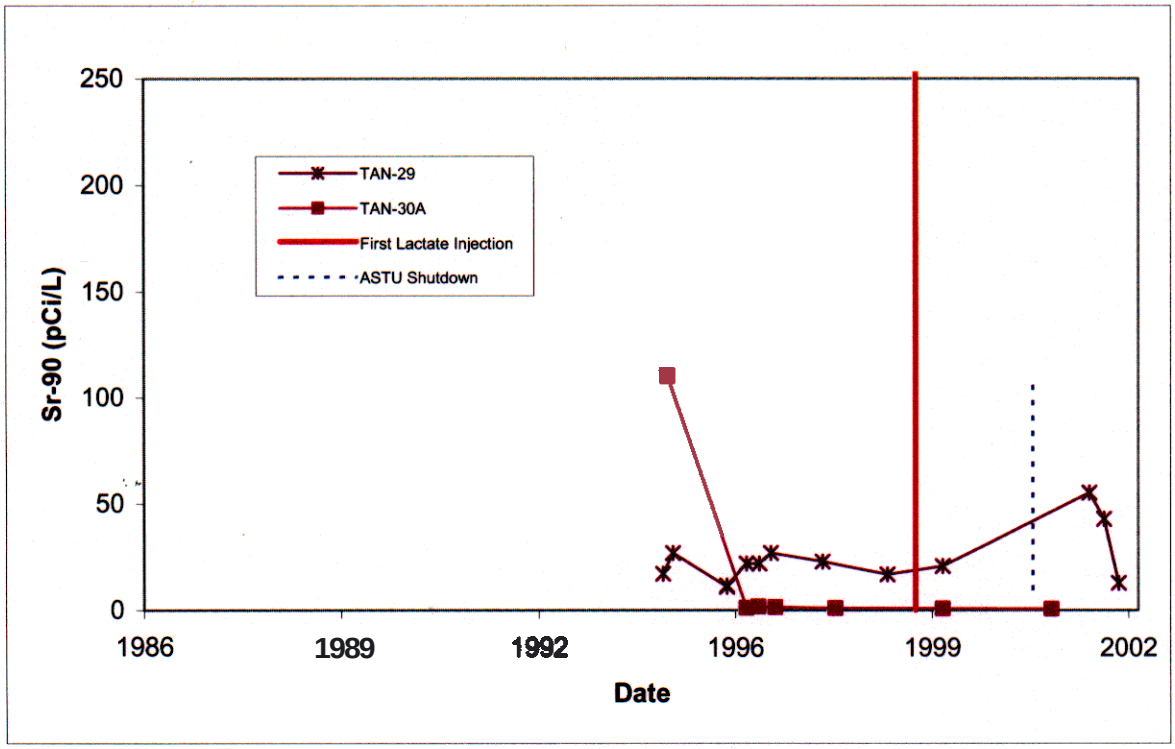

Figure 7-12. Strontium-90 concentrations in TAN-29 and MA.

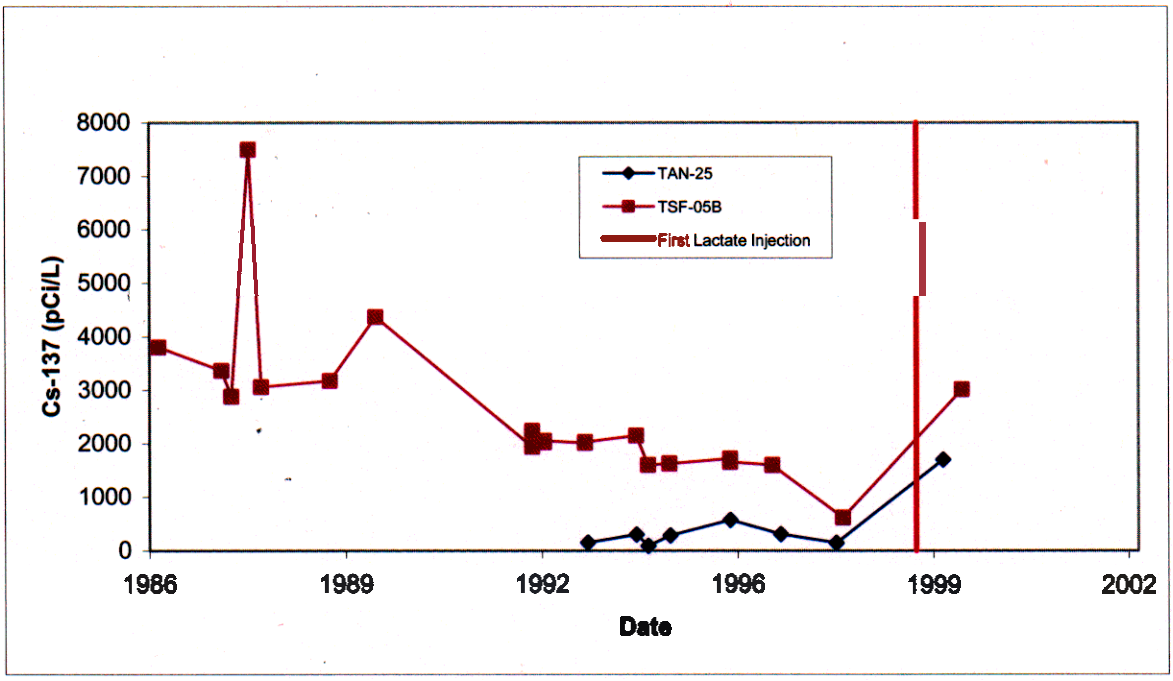

Figure 7-13. Cesium-137 concentrations in TSF-OSB and TAN-25.

Figure 7-14 presents the strontium-90 concentrations for wells along the plume axis at varying distances from TSF-05. This plot shows that strontium-90 activities decline significantly with distance from TSF-05. Strontium-90 concentrations are less than the MCL (8 pCi/L) at distances more than 150 m (500 ft) downgradient from the injection well. An observed decay rate can be estimated using the following first-order equation:

$$\ln\left(\frac{C_t}{C_o}\right) = -\lambda t \qquad (3)$$

where

C_t = contaminant concentration at time t

C_o = initial contaminant concentration

λ = decayconstant

t = time.

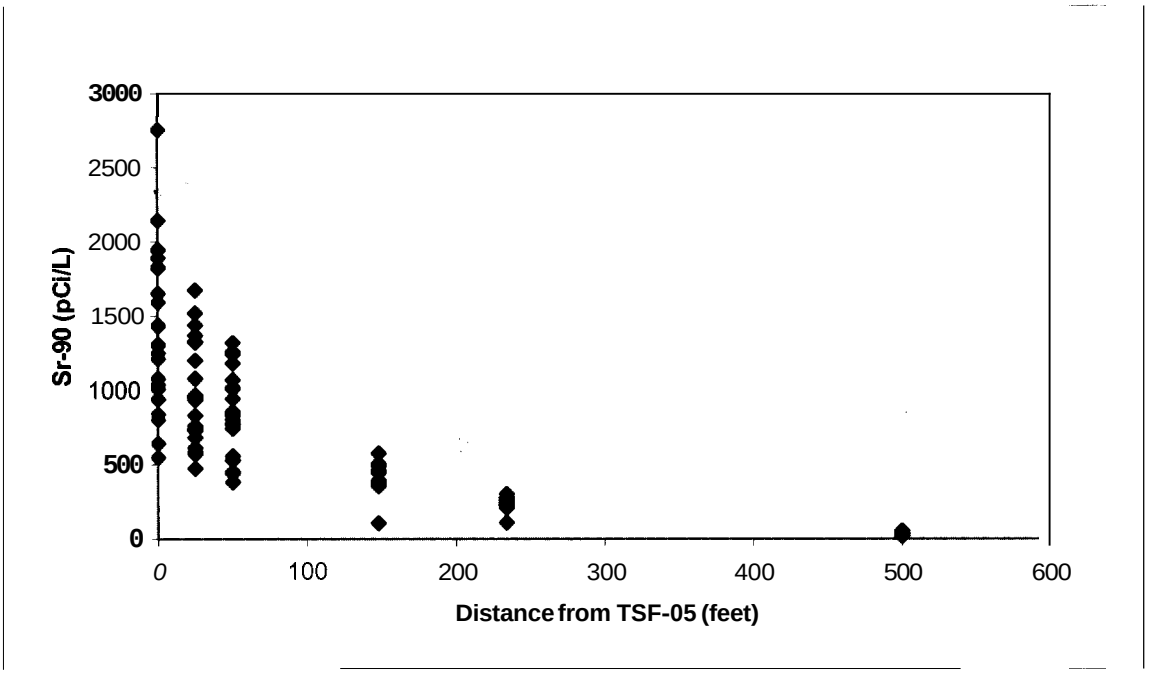

Figure 7-14. Strontium-90 concentration decreases with distance from injection well TSF-05.

To illustrate this relationship graphically, the concentration data were normalized by taking the ratio of the measured concentration to the initial concentration (represented by the average concentration at TSF-05). Next, the concentration ratios were transformed by their natural log and the distance from TSF-05 was converted to travel time, assuming average groundwater velocity to be 0.35 ft/day (as discussed in Section 7.2.3). The transformed data are plotted in Figure 7-15. From this figure, it is clear that the natural log of the strontium ratios can be related to time using a first-order equation. Application of a first-order linear regression yielded a slope of –0.96. An examination of the regression coefficient (0.92) and the regression residuals indicates that the regression provides a good fit of the data, and that the underlying statistical assumptions were met (residuals were normally distributed and centered about zero).

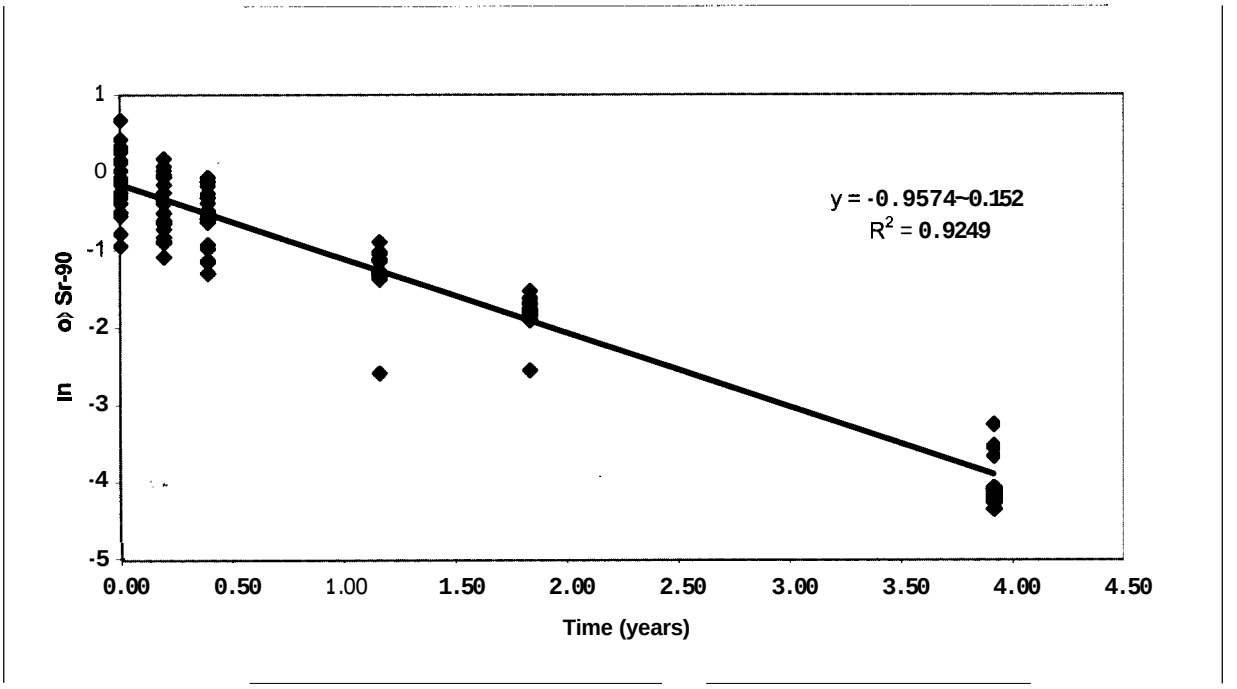

Figure 7-15. Natural log of strontium-90 relative concentrations versus travel time from TSF-05.

Thus, from Figure 7-15, the observed decay rate, λ, is related to the slope of the regression line by:

$$\lambda_{observed} = -\frac{\ln\left(\frac{C}{C_0}\right)}{t} = -m = 0.96/year \qquad (4)$$

where

t = time for the contaminant to travel from TSF-05 to the observation point

m = slope of the linear regression model.

The observed decay coefficient, 0.96 year^{-1} (corresponding to an observed half-life of 0.7 years) is 40 times the decay coefficient for radioactive decay of strontium-90, 0.024 (corresponding to a radioactive decay half life of 28.8 years). Hence, processes other than radioactive decay are reducing concentrations of strontium-90. These processes probably include sorption and co-precipitation with calcite.

7.3.3 Consideration of Natural Variability

Measurement error is inherent in all sampling data due to a number of analytical, sampling, and natural sources. Sample precision was discussed previously in Section 6 by considering the results of duplicate samples. In addition to the combined effects of measurement error, however, natural variability in contaminant concentrations also affects the interpretation of groundwater data. Annual samples, collected to track MNA performance, may represent a wide range in concentration values. To illustrate this point, monthly strontium and tritium data collected as part of **ISB** operations are overlain on the

annual data reported in the TAN historical data tables (Figures 7-16 through 7-19). These figures show the fluctuation in strontium-90 and tritium data throughout the course of a year. It should be noted that the lactate injections in TSF-05 are thought to contribute to the amplitude in variation in nearby wells. Fluctuations in distal zone wells, and in medial zone wells following completion of ISB and NPTF operations, should be less extreme than those presented in these figures because dispersion will dampen these variations.

This graphical analysis clearly illustrates that, for radionuclide data, a single sample point used to represent an annual time period has variability associated with it based on the time of year it was collected. For example, at TAN-28 (Figure 7-19), the 2001 annual sample value for tritium taken in May was 3,720 pCi/L. However, the April and June samples showed concentrations of 3,160 and 4,710 pCi/L, respectively. This observation is important to consider when evaluating future data. Abnormally high or low values may occasionally be observed in any given annual sample. This further supports the conclusion that only with consistent monitoring over long time periods will MNA performance be accurately measured for radionuclides, as well as for TCE. It is difficult to draw conclusions about expected variability based on depth in the aquifer or distance from TSF-05. However, it is clear that significant fluctuations are expected in annual data.

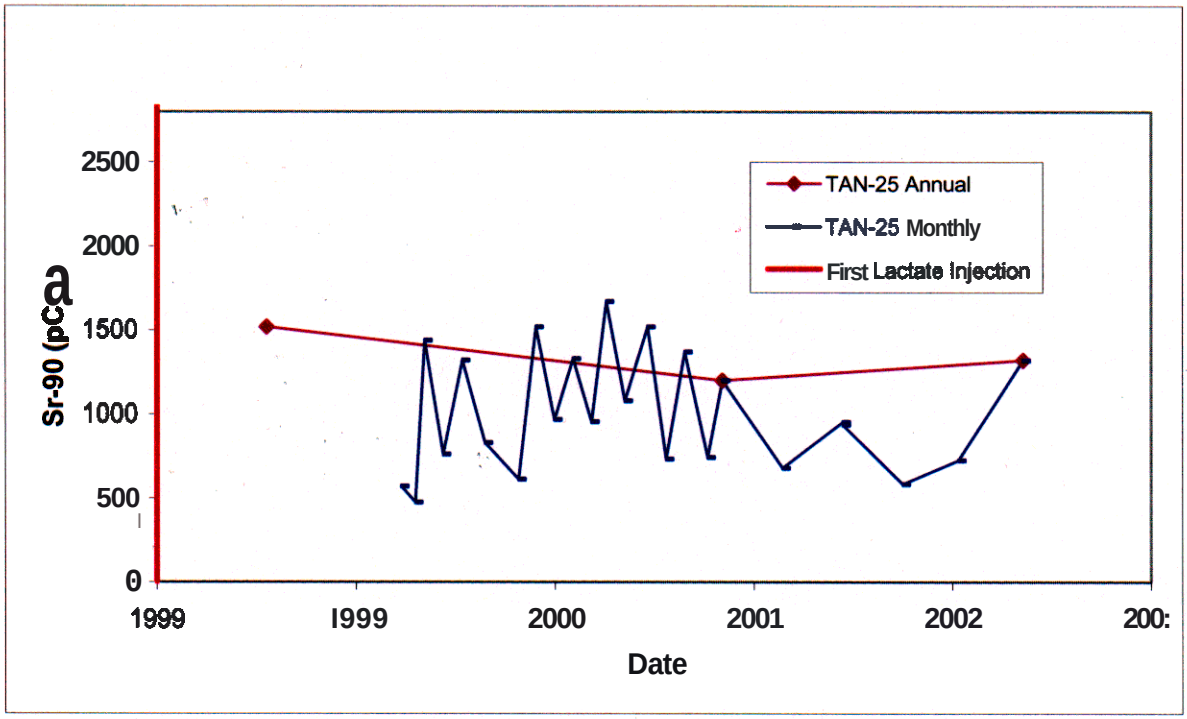

Figure 7-16. Comparison of annual data to monthly strontium-90 data at TAN-25.

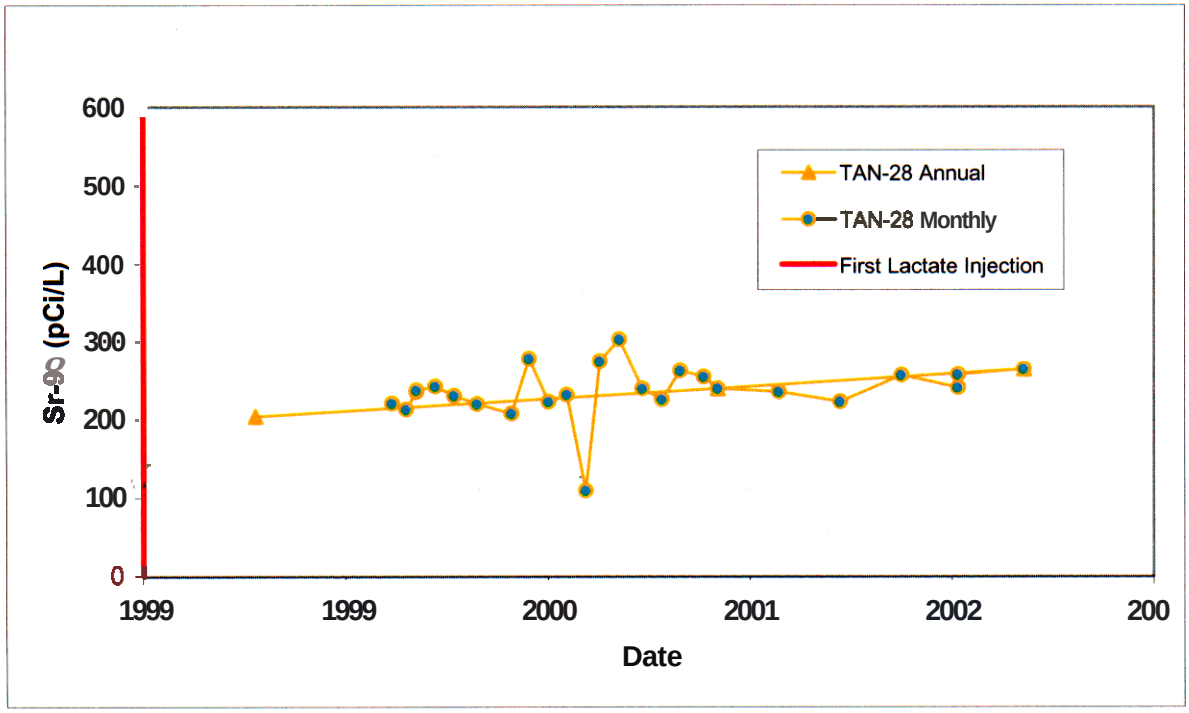

Figure 7-17. Comparison of annual data to monthly strontium-90 data at TAN-28.

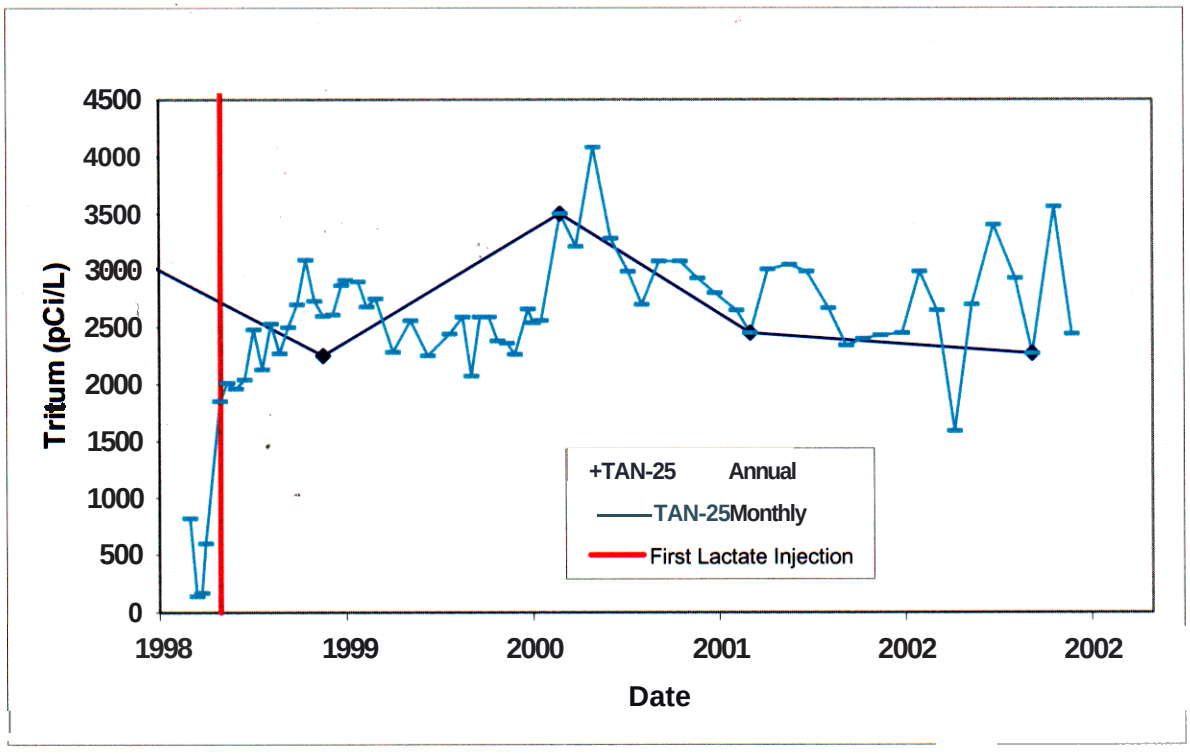

Figure 7-18. Comparison of annual data to monthly tritium data at TAN-25.

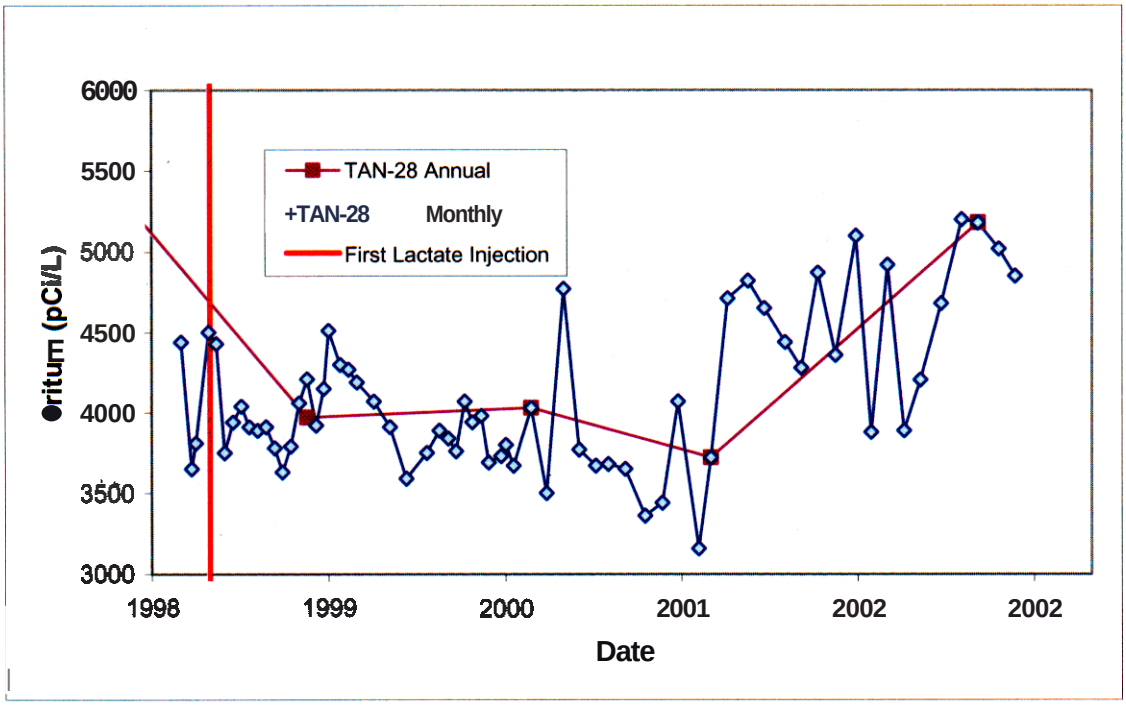

Figure 7-19. Comparison of annual data to monthly tritium data at TAN-28.

7.4 Analysis of Water Level Data

The water-table contour map of TAN constructed using water-level data collected during 2002 (Figure 4-1) indicates that regional groundwater flow is to the southeast with a south to southwestern component of flow near well TAN-57. Within the TCE plume, flow direction is generally to the south to southeast. Subregional groundwater flow is consistent with the regional observations to include the south-southeast localized flow near well TAN-57 (Figure 4-3).

The local direction of groundwater flow at TAN diverges from the regional direction of groundwater flow, which is to the southwest. This divergence may be attributed to local heterogeneities associated with the complex stratigraphic relations of the fractured basalt aquifer and with nearby buried features associated with volcanic rift zones. Based on comparison of 2002 water-level data to water-level data collected in previous years, the groundwater flow field at TAN has not changed significantly with the exception of a slight groundwater mound that has formed around TAN-48 and TAN-53A in response to injection of water from the NPTF.

Water-level contours indicate about three feet of change in water level over the area of the TCE plume. The gradient increases southeast of the 5 µg/L isopleth with a water-level change of about 13 ft between TAN-58 and ANP-9. The hydraulic gradient between TAN-48, near NPTF, and TAN-52, along the plume's longitudinal axis, averages 3.9E-4 ft/ft (based on a measured water level at TAN48 of 4574.35 ft amsl, a measured water level at TAN-52 of 4572.59 ft amsl, and the distance between the two wells of 4,539 ft).

Water levels in nearby wells that were completed at different depth intervals were compared to evaluate the vertical hydraulic gradient in the aquifer. This comparison indicates that vertical gradients exist, with upward gradients in some wells and downward in others. These differences probably reflect the complex stratigraphic sequence of the basaltic aquifer (see Table 4-1).

8. SUMMARY

Water-chemistry data collected during FY 2002 MNA activities were analyzed in support of the upcoming evaluation and reporting activities of the MNA remedial action. These data collection and analytical activities document operational conditions prior to the MNA remedial action and support hture interpretation of the monitoring data. The data analysis activities included evaluation of baseline TCE concentrations and trends, documentation of observed degradation rates for TCE and cis-DCE, summary of results of vertical profile samples, documentation of the basis of the current estimate of the preoperational TCE plume boundaries, documentation of the numerical model verification and update work, evaluation of baseline radionuclide concentrations and trends, and a summary of water level data.

8.1 Evaluation of Baseline TCE Concentrations and Trends

Temporal TCE trends are generally consistent with predicted trends.

Prior to startup of NPTF operations, TCE concentrations from wells located near the downgradient boundary of the medial zone were consistently less than 1,000 µg/L, indicating that groundwater in this area would meet the operational parameters of the MNA component of the remedy. TCE concentrations in water samples collected from these wells since the start of NPTF are not useful for assessing natural degradation trends because of the local effects of the treatment unit.

Historical TCE concentration data in water from USGS-24 were statistically analyzed using a linear regression technique to determine whether temporal concentration trends could be distinguished. The analysis indicated that a decreasing trend in concentration can be clearly defined in the post-breakthrough TCE data set at this location. Locations hrther downgradient are expected to have lower and broader concentration peaks with very gradual reductions in concentration over long time periods. Statistical evaluation of TCE data sets from distal zone monitoring wells located hrther downgradient may require more robust techniques and longer period of record to verify the presence or absence of meaninghl trends.

The precision of sample measurements was evaluated by considering the variability between sets of duplicate samples during 2002. The results indicated that the samples were relatively homogenous and that the analytical techniques yielded consistent and repeatable results.

8.2 Observed Degradation Rates for TCE and cis-DCE

Available data were analyzed using the tracer-corrected method to determine the rate that TCE is degrading in the OU 1-07B groundwater plume. Because the concentrations of tritium are rapidly declining through natural radioactive decay (tritium has a relatively short half-life), the tritium data collected during MNA operations will become increasingly less reliable for calculation of the TCE degradation rate. For this reason, the available data were used in this document to calculate a best estimate of the degradation rate. It is not anticipated that the degradation rate will be recalculated in hture years. Results of this analysis yielded an estimate of TCE half-life of 13.2 years with an upper bound to the 95% confidence interval corresponding to a half-life of 14.6 years. Because the data yielded good statistical correlation, and hrther analysis of PCE data also corroborated the tracer corrected method, it was concluded that this estimate will support hture evaluation of MNA performance.

The degradation rate for cis-DCE also was examined. The estimated cis-DCE half-life was 8.4 years (with an upper 95% confidence limit corresponding to a half-life of 9.3 years). This data indicate that degradation of cis-DCE is occurring in concert with TCE degradation and at a faster rate, as expected from its properties.

8.3 Summary of FLUTe™ Liner Sampling Results

During FY 2002, stratified samples were collected from four MNA wells (TAN-51, -52, -54, and -55) that have been fitted with multiport FLUTe™ samplers. The similar profiles detected for several analytes in the FLUTe™ wells demonstrated the overall consistency of the FLUTe™ data.

The well-to-well variability demonstrates that vertical concentration profiles are a function of local stratigraphy, as opposed to large-scale preferential flow or attenuation processes acting at different rates with depth.

The ratio of TCE to tritium was relatively constant at all depths in the FLUTe™ wells. This consistency hrther supports the validity of the degradation rate constant calculation.

8.4 Basis of the Current Estimate of the Pre-operational TCE Plume Boundaries

Data collected since 1997 indicated that the size and shape of the 5 μg/L isopleth that defines the plume boundary have been relatively stable.

The ability to locate the 5 μg/L isopleth is limited by well spacing. At the current leading edge of the plume, several wells are spaced approximately 500 to 1,000 ft apart; therefore, the overall uncertainty in the estimate of the location of the leading edge of the plume cannot exceed 1,000 ft and is probably less than half that distance.

8.5 Numerical Modeling Verification and Update

During FY 2002, the MNA groundwater flow and transport model, developed using TETRAD, was converted to a MODFLOW/MT3DMS format. Preliminary calibration was conducted on the model conversion. The converted model will be used to evaluate the effect of revised estimates of the TCE degradation half-life on MNA.

8.6 Evaluation of Baseline Radionuclide Concentrations and Trends

The data indicate that radionuclide concentrations in the distal portion of the plume are below their respective MCLs.

Radionuclide concentrations were monitored in selected wells near TSF-05 to verify the assumption that radionuclides will attenuate naturally through processes of sorption and radioactive decay to meet cleanup objectives throughout the plume. The data indicate that naturally attenuation processes already are having a measurable effect on radionuclide concentrations at some locations. Tritium concentrations for all MNA wells are presently less than the MCL.

Strontium-90 concentrations were less than 8 pCi/L at distances more than 150 m (500 ft) downgradient from the injection well. Strontium-90 concentrations in all of the wells within a distance of 150 m from TSF-05, except for TAN-30A, were above the MCL of 8 pCi/L. Increases in strontium-90 concentrations at TSF-05B, TAN-25, -37A, and -28 may be attributed to the mobilization of strontium-90 from the secondary source sludge, or to desorption and dissolution as a result of the organic acid production following lactate injection. Cesium-137 was also detected in TSF-05B and TAN-25. Cesium-137 concentrations at all other locations were consistently below the MDA.

The recent variability in tritium and strontium-90 concentrations near TSF-05 is consistent with the current understanding of the ISB treatment process.

Strontium-90 concentrations decrease along the plume axis at varying distances from TFS-05. An analysis of the data indicated that the observed decay rate is 40 times greater than that attributable to radioactive decay alone. The rapid decrease in strontium-90 concentrations may be attributable to sorption and co-precipitation with calcite in addition to radioactive decay. This analysis supports the conclusion that natural processes are attenuating concentrations of radionuclide contaminants.

Monthly tritium and strontium-90 concentrations in water from selected wells fluctuated with time in response to natural variability in contaminant concentrations and the combined effects of measurement error. Fluctuations in wells near TSF-05 may also be attributed to radionuclide mobilization in response to lactate injections. These data indicate that annual MNA sample results may represent a range in radionuclide concentration values, and that an annual sample has variability associated with it based on the time of year it was collected. Therefore, consistent sampling over several years will be required to evaluate trends with a high degree of confidence.

8.7 Water Level Data

Comparison of 2002 water-level data to past water-level data show that the groundwater flow field has not changed significantly, with the exception of a groundwater mound that has formed in response to extraction/injection of water as a result of operations at the NPTF.

As presented in section 4.2 and discussed in section 7.4, potential localized groundwater flow near well TAN-57 suggests a south-southeast flow direction (Figure 4-3). This would place well TAN-57 downgradient of the TCE plume as opposed to cross-gradient, as might be suggested by Figure 2-1. The well's down-gradient placement is also suggested by the 1.8 µg/L reported estimated analytical result for TCE (see historical data tables in Appendix C). This result has been reported as an estimated value since it was below the 5 µg/L detection limit. This may have some long-term implications to the monitoring strategy of the distal zone but requires additional information before changes, if any, are proposed. Based upon the presentations of data and discussions in this document, limited vertical profiling of well TAN-57 is being planned during the FY-03 annual sampling round. A total of five sets of samples are to be collected from various depths using portable sampling equipment following established low-flow sampling procedures to be analyzed for VOCs. The sampling depths were selected using wells logs (geophysical, acoustic televiewer, heat pulse flow meter, and video). This profiling will be used to evaluate the existence and (if VOCs are present) the vertical concentrations of VOCs within the open borehole of TAN-57 to better define the well's placement in regards to the distal zone's boundary. In addition to the vertical profiling action, hydraulic testing in TAN-57 would be beneficial in determining local the hydrogeologic properties.

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Appendix A

Guard Post Installation Drawing

Appendix A
Guard Post Installation Drawing

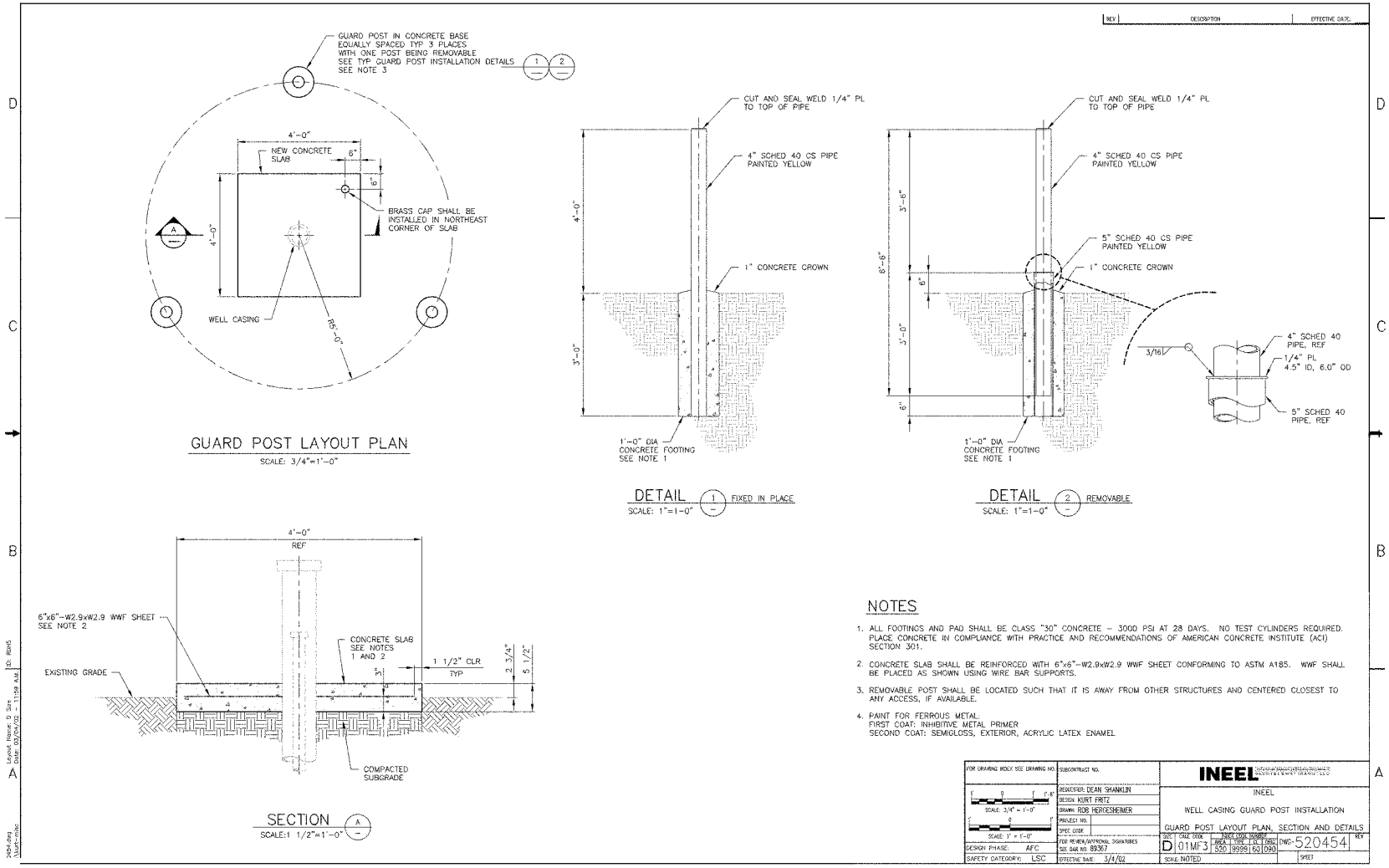

Figure A-1. Guard Post Installation.

Appendix B

Water Level Elevations

Appendix B

Water Level Elevations

Procedure followed to correct water level measurements for barometric pressure effects:

Introduction

The importance of collecting accurate water level data is well noted in the literature (Barcelona et. al. 1985, and Spane 1999). The data provide information on the directions (horizontal and vertical) of groundwater flow and the area's hydraulic gradient. However, it is well established that barometric pressure fluctuations can have a discernible impact on well water-level measurements. These fluctuations represent an aerial, blanket stress applied directly to land surface and to the open well water-level surface (Spane 1999).

Conceptually, a stabilized borehole water level will reflect the pressure of groundwater in the subsurface material exposed along the sides of the borehole or well. Under suitable conditions, the borehole water level and the groundwater level will be the same, and the former can be used to determine the latter (ASTM 1992). However, when subsurface materials are not exposed to a borehole, such as material which is sealed off with casing, the borehole water levels may not accurately reflect the groundwater level. Consequently, the water level in a borehole does not necessarily bear a relationship to the groundwater level at the site. For an open, unconfined aquifer system, atmospheric pressure changes are transmitted instantaneously at the well but display a time-lagged response at the water table because air must move into or out of the overlying vadose zone to transmit the change in pressure.

The following procedure was followed to correct the water level measurements, taken on September 13, 2002, for barometric pressure effects:

Background

Water levels were measured by two field teams using three different electronic water level indicators (see Table B-1) during a single six-hour period (0900 to 1500 hours) on September 13, 2002. Two teams were used to reduce the time needed to collect water level readings from 74 TAN-area wells.

Table B-1. Water level indicators used during data collection

Make/Model	Serial Number	Comments
Solinst Model P4	30372	Used by Team A
Solinst Model 101	26674	Used by Team B
Heron Instrument Dipper-T	06340	Used in wells containing FLUTe® Liners

The specialty water level indicator (Heron Instrument Dipper-T) was needed to collect water levels in the wells containing FLUTe® Liner due the small access tubes (1/2 inch diameter).

Duplicate water level measurements were taken using the two Solinst water level indicators at four different wells to assist in determining differences between tape lengths and for use in determining barometric pressure influences on the water level readings. The Heron Instrument Dipper-T indicator could not be used in a standard monitoring well due to the metal drop tubes making contact between the

two contacts prior to reaching the water level. To determine measurement differences, the Solinst Model 101 tape was laid out on the ground surface next to the Heron Instrument Dipper-T tape and a length difference was recorded.

Process Followed

Actual water level TOC measurements were adjusted to reflect measurements that would have been taken using the Model 101. Measurements taken with the Model P4 were adjusted by subtracting 0.015 ft to account for tape length differences as determined by duplicate measurements at Wells TAN-04 and -05 (see Table B-2). Tape length comparisons between the Solinst Model 101 and the Heron Instrument Dipper-T revealed that the Solinst Model 101 tape was 0.01 ft shorter at 200 ft of tape. Heron Instrument Dipper-T measurements were adjusted by subtracting 0.01 ft per 200 ft length measured.

Table B-2. Comparison of water level measurements between indicators.

	Solinst Model P4 Measurement		Solinst Model 101 Measurement		Difference
Well	(TOC in ft)	Time of Day	(TOC in ft)	Time of Day	(ft)
TAN-04	229.75	0915	229.77	0911	-0.02
TAN-05	230.34	0918	230.35	0919	-0.01
TAN-27	208.38	1456	208.47	1127	-0.09
TAN-50	216.88	1451	216.96	1211	-0.08

To adjust the water level measurements for atmospheric pressure changes, the barometric pressure at TAN was continuously monitored and recorded using an In Situ Hermit 3000 Datalogger (SN 45228) with the data illustrated in Figure B-1. From time 0900 to 1130, the trend line for plotted barometric pressure readings had a slope of 5E-05 or essentially 0 (Figure B-2). During this time interval, the barometric pressure remained relatively constant at an average pressure of 25.27 inches of Hg, and TOC measurements were not adjusted. However, from time 1130 to 1500, the trend line for plotted barometric pressure readings had a slope of 4.6E-3, illustrating a pressure drop from 25.267 to 25.208 inches of Hg (Figure B-3). A decrease in barometric pressure would result in an increase in the water level elevation (decrease in TOC measurements). For water level measurements made between the hours of 1130 to 1500, adjustments were made for the linear barometric pressure drop using Figure B-4. Resultant adjusted water level measurements are listed in Table B-3 with the corresponding calculated water level elevations.

The tape length adjustments made and described above are straightforward. The barometric pressure adjustments were calculated based upon information from Spane (1999) where it is stated that total aquifer head can be calculated from well measurements by adding the incremental change of atmospheric pressure at the time of measurement directly to the observed water level elevation measurement.

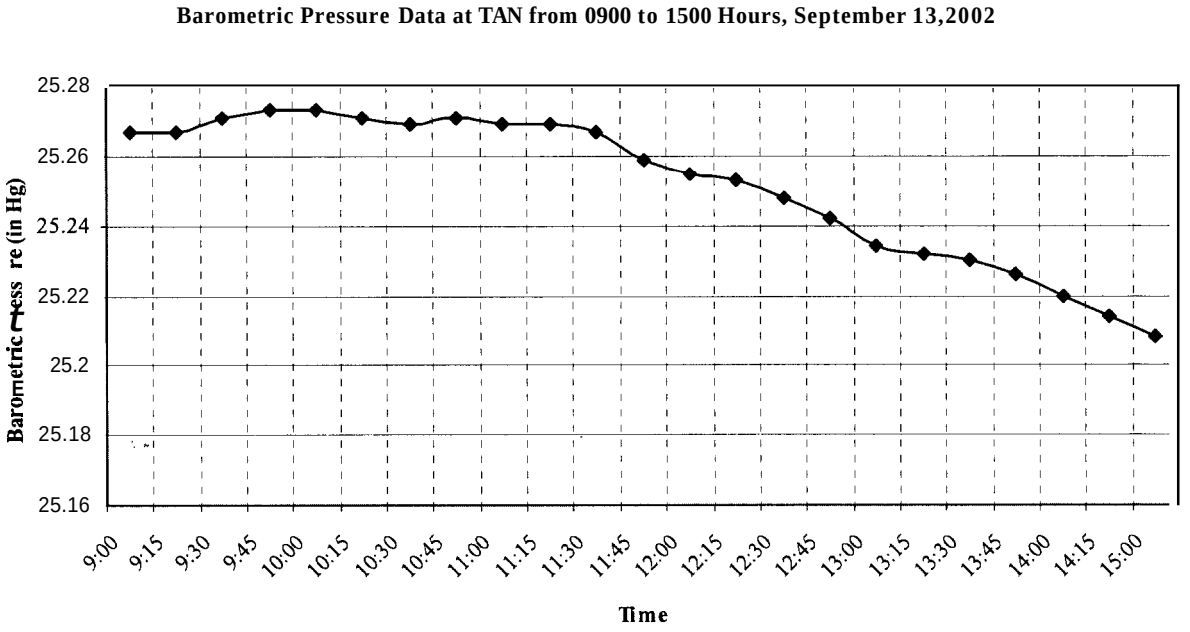

Figure B-1. Barometric Pressure Data at TAN from 0900 to 1500 Hours, September 13,2002.

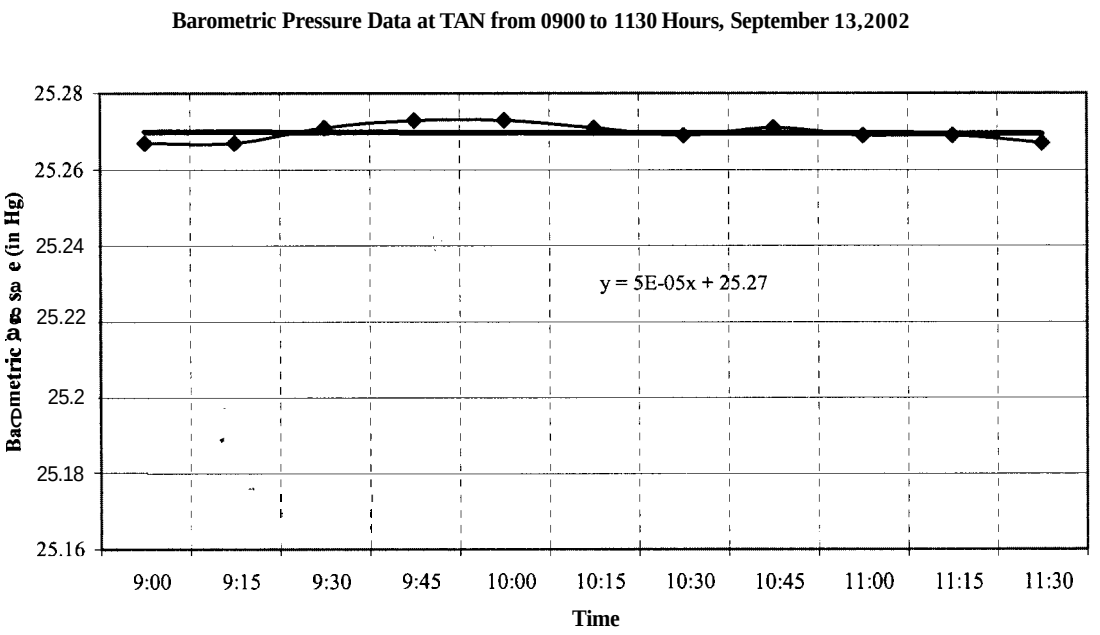

Figure B-2. Barometric Pressure Data at TAN from 0900 to 1130 Hours, September 13,2002.

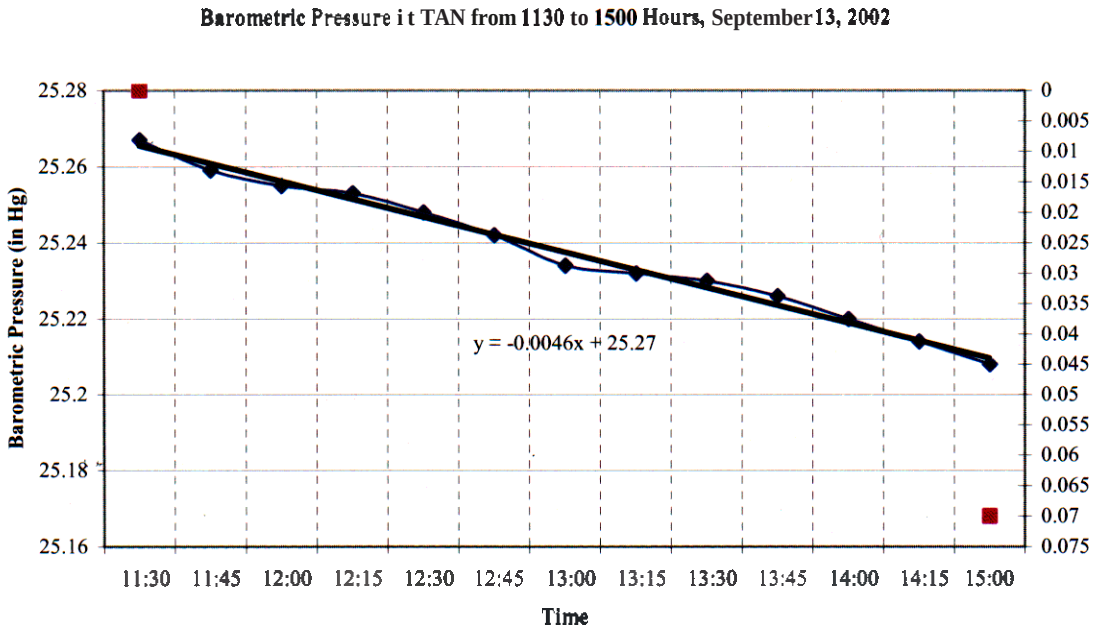

Figure B-3. Straight-line linear fit of Barometric Pressure Data at TAN from 1130 to 1500 Hours.

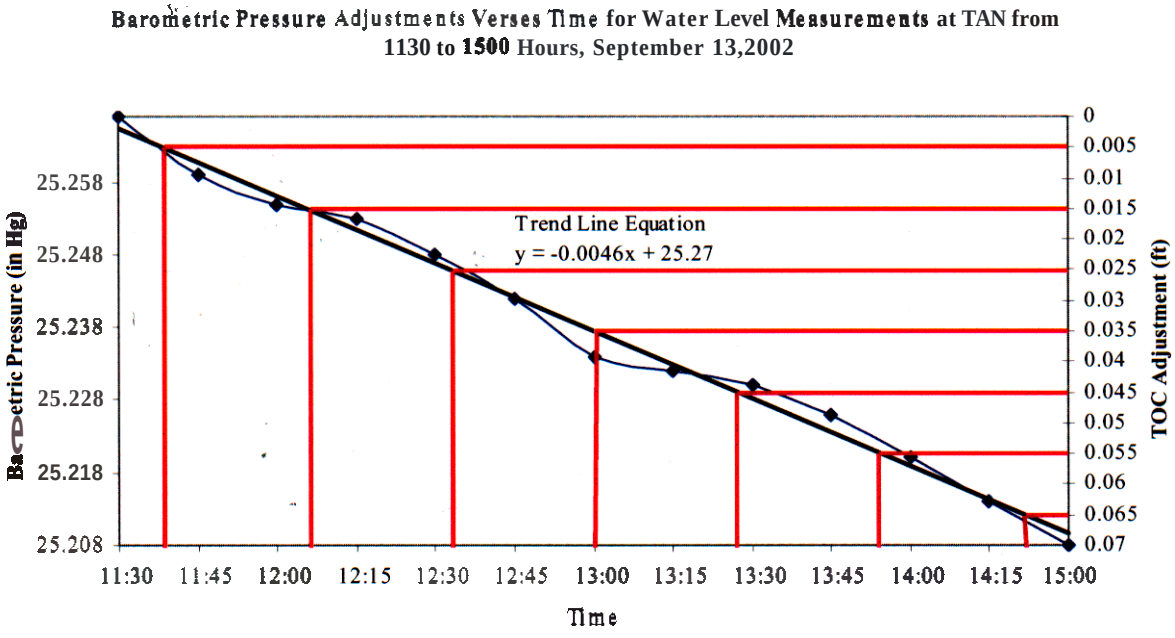

Figure B-4. Graph used to adjust water level data for barometric pressure changes for reading taken from 1130 to 1500 hours, September 13,2003.

Table B-3. Adiusted water level data. September 13. 2002

Well	Easting" NAD27	Northing" NAD27	*MP* Elev.[b] (ftamsl)	Water Level Indicator Used	Depth to Water TOC[c] (ft)	Adjusted TOC[c] for Tape Length (ft)	Time Measurement was Taken	Elapsed Time (min)	Adjusted TOC[c] for Barometric Pressure (ft)	Water Elevation[b] (ft amsl)	Water Elevation[b] (m amsl)
ANP-5	—	—	4874.65	Model P4	300.57	300.55	1010	70	300.55	4574.10	1394.19
ANP-6	—	—	4797.05	Model P4	222.87	222.85	1117	137	222.85	4574.20	1394.22
ANP-7	—	—	4936.68	Model P4	361.72	361.70	1100	120	361.70	4574.98	1394.45
ANP-9	—	—	4788.24	Model P4	229.46	229.44	1229	209	229.46	4558.78	1389.52
ANP-10	—	—	4787.64	Model P4	227.58	227.56	1235	215	227.59	4560.05	1389.90
FET-DISPOSAL	—	—	4785.85	Model 101	211.78	211.78	1100	120	211.78	4574.07	1394.18
GIN-1	—	—	4788.11	Model P4	216.78	216.76	1411	311	216.82	4571.29	1393.33
GIN-2	—	—	4787.87	Model P4	215.95	215.93	1403	303	215.99	4571.88	1393.51
GIN-3	—	—	4788.43	Model P4	216.72	216.70	1353	293	216.75	4571.68	1393.45
GIN-4	—	—	4788.08	Model P4	216.24	216.22	1406	306	216.28	4571.80	1393.48
GIN-5	—	—	4788.31	Model P4	216.32	216.30	1358	298	216.36	4571.95	1393.53
Mw-2	—	—	4789.43	Model P4	217.65	217.63	1344	284	217.68	4571.75	1393.47
NONAME	—	—	4786.00	Model P4	213.68	213.66	1135	155	213.66	4572.34	1393.65
OWSLEY-2	—	—	4785.95	Model P4	230.10	230.08	1218	138	230.08	4555.87	1388.63
P&W-1	—	—	4897.22	Model P4	323.01	322.99	1040	100	322.99	4574.23	1394.23
P&W-2	—	—	4892.91	Model P4	318.69	318.67	1035	95	318.67	4574.24	1394.23
P&W-3	—	—	4887.43	Model P4	312.91	312.89	1018	78	312.89	4574.54	1394.32
PSTF	—	—	4788.23	Model P4	215.34	215.32	1144	164	215.33	4572.90	1393.82
TAN-04	—	—	4803.61	Model 101	229.77	229.77	911	11	229.77	4573.84	1394.11
TAN-05	—	—	4804.03	Model 101	230.35	230.35	919	19	230.35	4573.68	1394.06
TAN-06	—	—	4788.73	Model P4	215.19	215.17	1308	248	215.21	4573.52	1394.01
TAN-07	—	—	4788.65	Model P4	215.05	215.03	1304	244	215.07	4573.58	1394.03
TAN-08	—	—	4791.58	Model P4	217.91	217.89	1435	335	217.96	4573.62	1394.04
TAN-09	—	—	4782.62	Model 101	208.60	208.60	1013	73	208.60	4574.02	1394.16
TAN-10	—	—	4782.73	Model 101	208.45	208.45	1145	165	208.46	4574.27	1394.24
TAN-10A	—	—	4782.63	Model 101	208.68	208.68	1142	162	208.69	4573.94	1394.14
TAN-11	—	—	4782.83	Model 101	208.72	208.72	1148	168	208.73	4574.10	1394.19

Table B-3. (continued)

Well	Easting" NAD27	Northing" NAD27	*MP* Elev.[b] ift amsl)	Water Level Indicator Used	Depth to Water TOC[c] (ft)	Adjusted TOC[c] for Tape Length (ft)	Time Measurement was Taken	Elapsed Time (min)	Adjusted TOC[c] for Barometric Pressure (ft)	Water Elevation[b] ift amsl)	Water Elevation[b] (m amsl)
TAN-12	—	—	4782.78	Model 101	208.73	208.73	1151	171	208.74	4574.04	1394.17
TAN-13A	—	—	4782.41	Model P4	208.62	208.60	1500	360	208.67	4573.74	1394.08
TAN-14	—	—	4782.69	Model P4	209.56	209.54	1502	362	209.61	4573.08	1393.87
TAN-15	—	—	4788.88	Model P4	215.58	215.56	1313	253	215.60	4573.28	1393.94
TAN-16	—	—	4788.81	Model P4	215.47	215.45	1321	261	215.49	4573.32	1393.95
TAN-18	—	—	4804.37	Model 101	231.10	231.10	935	35	231.10	4573.27	1393.93
TAN-19	—	—	4805.67	Model 101	231.88	231.88	931	31	231.88	4573.79	1394.09
TAN-20	—	—	4782.88	Model P4	208.94	208.92	1507	367	208.99	4573.89	1394.12
TAN-21	—	—	4789.20	Model P4	216.79	216.77	1424	324	216.84	4572.36	1393.66
TAN-22A	—	—	4788.76	Model P4	215.52	215.50	1326	266	215.55	4573.21	1393.91
TAN-23A	—	—	4788.60	Model P4	215.39	215.37	1323	263	215.42	4573.18	1393.91
TAN-24A	—	—	4790.93	Model P4	219.14	219.12	1349	289	219.17	4571.76	1393.47
TAN-27	—	—	4782.41	Model 101	208.47	208.47	1127	147	208.47	4573.94	1394.14
TAN-28	—	—	4784.02	Model 101	210.22	210.22	955	55	210.22	4573.80	1394.09
TAN-29	—	—	4783.61	Model 101	210.15	210.15	1025	85	210.15	4573.46	1393.99
TAN-30A	—	—	4784.03	Model 101	209.78	209.78	1000	60	209.78	4574.25	1394.23
TAN-31	—	—	4784.94	Model 101	210.55	210.55	1009	69	210.55	4574.39	1394.27
TAN-32	—	—	4787.42	Model 101	213.54	213.54	1344	284	213.59	4573.83	1394.10
TAN-33	—	—	4800.41	Model 101	226.66	226.66	939	39	226.66	4573.75	1394.08
TAN-34	—	—	4785.19	Model 101	211.43	211.43	1112	132	211.43	4573.76	1394.08
TAN-35	—	—	4784.54	Model 101	210.71	210.71	1109	129	210.71	4573.83	1394.10
TAN-36	—	—	4796.35	Model 101	222.55	222.55	1301	241	222.59	4573.76	1394.08
TAN-37	—	—	4784.35	Model 101	210.30	210.30	1004	64	210.30	4574.05	1394.17
TAN-41	—	—	4785.94	Model 101	212.06	212.06	1401	301	212.12	4573.82	1394.10
TAN-42	—	—	4802.58	Model 101	228.79	228.79	1407	307	228.85	4573.73	1394.07
TAN-43	—	—	4801.78	Model 101	228.27	228.27	1411	311	228.33	4573.45	1393.99
TAN-44	—	—	4800.75	Model 101	228.07	228.07	1415	315	228.13	4572.62	1393.73

Table B-3. (continued)

Well	Easting" NAD27	Northing" NAD27	*MP* Elev.[b] ift amsl)	Water Level Indicator Used	Depth to Water TOC[c] (ft)	Adjusted TOC[c] for Tape Length (ft)	Time Measurement was Taken	Elapsed Time (min)	Adjusted TOC[c] for Barometric Pressure (ft)	Water Elevation[b] ift amsl)	Water Elevation[b] (m amsl)
TAN-45	—	—	4797.71	Model 101	223.91	223.91	1307	247	223.95	4573.76	1394.08
TAN-46	—	—	4796.36	Model 101	222.55	222.55	1303	243	222.59	4573.77	1394.09
TAN-47	—	—	4790.51	Model P4	216.15	216.13	1441	341	216.20	4574.31	1394.25
TAN-48	—	—	4790.20	Dipper-T	215.84	215.83	1219	199	215.85	4574.35	1394.26
TAN-50	—	—	4790.84	Model 101	216.90	216.90	1211	191	216.92	4573.92	1394.13
TAN-51	—	—	4788.59	Dipper-T	214.78	214.77	1232	212	214.79	4573.80	1394.09
TAN-52	—	—	4788.00	Dipper-T	215.39	215.38	1251	231	215.41	4572.59	1393.73
TAN-54	—	—	4789.36	Dipper-T	215.81	215.80	1239	219	215.83	4573.53	1394.01
TAN-55	—	—	4789.64	Dipper-T	215.80	215.79	1226	206	215.81	4573.83	1394.10
TAN-56	—	—	4790.05	Model P4	218.67	218.65	1338	278	218.70	4571.35	1393.35
TAN-57	—	—	4790.30	Model P4	221.33	221.31	1417	317	221.37	4568.93	1392.61
TAN-58	—	—	4791.70	Model P4	219.66	219.64	1333	273	219.69	4572.01	1393.55
TAN-CH2-1	—	—	4791.94	Model P4	214.24	214.22	1430	330	214.29	4577.65	1395.27
TAN-CH2-2	—	—	4791.94	Model P4	220.11	220.09	1433	333	220.16	4571.78	1393.48
TAN-D1	—	—	4789.21	Model P4	215.08	215.06	1446	346	215.13	4574.08	1394.18
TAN-D3	—	—	4780.00	Model P4	205.87	205.85	953	53	205.85	4574.15	1394.20
USGS-07	—	—	4790.81	Model P4	219.19	219.17	1154	174	219.18	4571.63	1393.43
USGS-24	—	—	4796.99	Model 101	223.19	223.19	944	44	223.19	4573.80	1394.09
USGS-25	—	—	4850.87	Model P4	276.81	276.79	1028	88	276.79	4574.08	1394.18
USGS-26	—	—	4790.65	Model P4	216.80	216.78	1253	233	216.81	4573.84	1394.11

a. Data withheld due to Homeland Security issues.
b. amsl = above mean sea level
c TOC = top of casing. Measurements represent the distance from the top-of-casing (measurement point) to the water level.

Appendix C

Historical Data Tables

See Excel file for historical data tables on CD (attached)

Appendix D

Volatile Organic Compound and Radiological Quality Assurance/Quality Control Data for the Fiscal Year 2002 Sampling Event

Appendix D

Volatile Organic Compound and Radiological Quality Assurance/Quality Control Data for the Fiscal Year 2002 Sampling Event

Table D-1. VOC quality assurance/quality control data for the FY-2002 sampling program.

Sample Delivery Group Sample ID	Description	Date	VC (µg/L)	1,1-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	cis-DCE (µg/L)	trans-DCE (µg/L)
1WR08701VA								
1WR08701VA	Trip Blank	10-Jun-02	5 U	10 U	5 U	5 U	5 U	5 U
1WR08401VA								
1WR08401VA	PES	26-Jun-02	43	47	19	12	21	26
1WR09901VA	Field Blank	25-Jun-02	5 U	10 U	5 U	5 U	5 U	5 U
1WR08901VA	Trip Blank	20-Jun-02	5 U	10 U	5 U	5 U	5 U	5 U
1WR00901VE								
1WRO8801VA	Trip Blank	17-Jun-02	5 U	10 U	5 U	5 U	5 U	5 U
1WR09801VA	Field Blank	17-Jun-02	5 U	10 U	5 U	5 U	5 U	5 U
1WR17201VA								
1WR17201VA	Trip Blank	8-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR17301VA	Rmsate	11-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR09101VA	Trip Blank	8-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WRO8501VA	PES	9-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR02101VA								
1WR16801VA	Field Blank	15-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR17401VA	Rmsate	15-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR09201VA	Trip Blank	15-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR02001VA								
1WR17901VA	Trip Blank	18-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR16901VA	Field Blank	22-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR17501VA	Rmsate	22-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR17801VA								
1WR09301VA	Trip Blank	25-Jul-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR09401VA								
1WR09401VA	Trip Blank	19-Aug-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR03901VA								
1WR09501VA	Trip Blank	26-Aug-02	5 U	5 U	5 U	5 U	5 U	5 U
1WR17601VA	Rmsate	28-Aun-02	5 U	5 U	5 U	5 U	5 U	5 U

Table D-1. (continued).

Sample Delivery Group Sample ID	Description	Date	VC (µg/L)	1,1-DCE (µg/L)	TCE (µg/L)	PCE (µg/L)	cis-DCE (µg/L)	trans-DCE (µg/L)
1WR09601VA								
1WR09601VA	Trip Blank	3-Sept-02	5 U	5 U	5 u	5 u	5 u	5 u
1WR04601VA								
1WR17001VA	Field Blank	21-Aug-02	5 U	5 U	5 u	5 u	5 u	5 u
1WR00801VA								
1WR18101VA	Trip Blank	15-Oct-02	5 U	5 U	5 u	5 u	5 u	5 u
1WR17101VA	Field Blank	15-Oct-02	5 U	5 U	5 u	5 u	5 u	5 u

U = non-detect

Table D-2. Tritium-strontium quality assurance/quality control data for the FY-2002 sampling program.

Sample Delivery Group Sample ID	Description	Date	Analysis	pCi/L	+/-	MDA
1WR00201RB						
1WR09901RB	Field Blank	25-Jun-02	Sr-90	0.0112	0.188	0.85
1WR09801RB	Field Blank	17-Jun-02	Sr-90	0.106	0.167	0.731
1WR00201R8						
1WR09801R8	Field Blank	17-Jun-02	H3	111	84.4	282
1WR09901R8	Field Blank	25-Jun-02	H3	166	87.6	283
1WR00701RB						
1WR16701RB	Field Blank	1-Jul-02	Sr-90	0.149	0.105	0.452
1WR16701R8	Field Blank	1-Jul-02	H3	54.1	81.1	271
1WR17301RB	Rmsate	11-Jul-02	Sr-90	0.0858	0.0967	0.446
1WR17301R8	Rmsate	11-Jul-02	H3	-8.5	80.2	272
1WR08401RB	PE Sample	17-Jul-02	Sr-90	4.00	0.921	0.71
1WRO8401R8	PE Sample	17-Jul-02	H3	6040	161	271
1WR00101RB						
1WR08601R8	PE Sample	27-Jun-02	H3	3070	126	274
1WR17201R8	Field Blank	8-Jul-02	H3	173	825	269
1WR17401R8	Rmsate	15-Jul-02	H3	25.3	80.6	271
1WR17401RB	Rmsate	15-Jul-02	Sr-90	0.132	0.103	0.442
1WR08601RB	PE Sample	27-Jun-02	Sr-90	8.09	1.15	0.965
1WR08501RB						
1WR17501RB	Rmsate	22-Jul-02	Sr-90	0.0969	0.085	0.335
1WR16801RB	Field Blank	15-Jul-02	Sr-90	0.0983	0.0935	0.371
1WR17201RB	Field Blank	8-Jul-02	Sr-90	0.0125	0.0971	0.413
1WR16901RB	Field Blank	22-Jul-02	Sr-90	0.0934	0.0967	0.387
1WR08501RB	PE Sample	11-Jul-02	Sr-02	19.5	2.66	0.626

Table D-2. (continued).

Sample Delivery Group Sample ID	Description	Date	Analysis	pCi/L	+/-	MDA
1WR17501R8	Rmsate	22-Jul-02	H3	-37.9	97.2	388
1WR16801R8	Field Blank	15-Jul-02	H-3	268	100	366
1WR08501R8	PE Sample	11-Jul-02	H-3	1940	137	355
1WR16901R8	Field Blank	22-Jul-02	H-3	-76.3	95.1	384
1WR17001RB						
1WR17001RB	Field Blank	21-Aug-02	Sr-90	0.583	0.214	0.821
1WR04501R8						
1WR17001R8	Field Blank	21-Aug-02	H-3	0	82.6	297
1WR03501R8						
1WR17601R8	Rmsate	28-Aug-02	H-3	-16	87.3	297
1WR03601RB						
1WR17601RB	Rmsate	28-Aug-02	Sr-90	0.205	0.113	0.404
1WR00801RB						
1WR17101RB	Field Blank	15-Oct-02	Sr-90	-0.168	0.158	0.856
1WR17101R8	Field Blank	15-Oct-02	H-3	-45.6	125	431

Appendix E

Sample Delivery Groups and Samples Collected for Volatile Organic Compound and Radiological Analysis

Appendix E

Sample Delivery Groups and Samples Collected for Volatile Organic Compound and Radiological Analysis

Table E-1. Sample delivery groups and samples collected for VOC analysis.

Sample Delivery Group Sample ID	Location	Date
1WR08701VA		
1WR08701VA	Trip Blank	10-Jun-02
1WR01201VA	TAN-03	12-Jun-02
1WR02601VA	TAN-24A	10-Jun-02
1WR02801VA	TAN-06	10-Jun-02
1WR01401VA	TAN-14	12-Jun-02
1WR02701VA	MW-2	10-Jun-02
1WR08401VA		
1WR08401VA	PE Sample	26-Jun-02
1WR00601VA	USGS-24	25-Jun-02
1WR09901VA	Field Blank	25-Jun-02
1WR00201VA	TAN-D3	26-Jun-02
1WR00301VA	TAN-34	26-Jun-02
1WR08901VA	Trip Blank	20-Jun-02
1WR01101VA	TAN-02	25-Jun-02
1WR03401VE	TAN-58	20-Jun-02
1WR00901VE		
1WR00901VE	TAN-05	19-Jun-02
1WR03101VE	TAN-17	17-Jun-02
1WR08801VA	Trip Blank	17-Jun-02
1WR03001VA	TAN-08	17-Jun-02
1WR02901VA	TAN-07	17-Jun-02
1WR01301VA	TAN-13A	17-Jun-02
1WR00501VA	TAN-19	19-Jun-02
1WR01302VA	TAN-13A	17-Jun-02
1WR09801VA	Field Blank	17-Jun-02
1WR17801VA		
1WR17801VA	TAN-21	25-Jul-02
1WR17802VA	TAN-21	25-Jul-02
1WR09301VA	Trip Blank	25-Jul-02
1WR03901VA		
1WR03901VA	TAN-48 (381)	26-Aug-02
1WR03701VA	TAN-48 (317)	26-Aug-02
1WR09501VA	Trip Blank	26-Aug-02
1WR17601VA	Rinsate	28-Aug-02
1WR04201VA	TAN-48 (225)	27-Aug-02
1WR03801VA	TAN-48 (345)	26-Aug-02
1WR03501VA	TAN-48 (225)	26-Aug-02
1WR07601VA	TAN-55 (265)	28-Aug-02
1WR07401VA	TAN-55 (221)	27-Aug-02
1WR00801VA	TAN-55 (404)	28-Aug-02
1WR07501VA	TAN-55 (251)	27-Aug-02
1WR07602VA	TAN-55 (265)	28-Aug-02
1WR07701VA	TAN-55 (317)	28-Aug-02
1WR07901VA	TAN-55 (373.5)	28-Aug-02
1WR07801VA	TAN-55 (332)	28-Aug-02
1WR08101VA	TAN-55 (439)	28-Aug-02
1WR04401VA	TAN-48 (381)	27-Aug-02
1WR04101VA	TAN-48 (431)	26-Aug-02
1WR04001VA	TAN-48 (412)	26-Aug-02
1WR03802VA	TAN-48 (345)	26-Aug-02
1WR04301VA	TAN-48 (273)	27-Aug-02
1WR03601VA	TAN-48 (273)	26-Aug-02
1WR05001VA		
1WR05001VA	TAN-51 (367)	20-Aug-02
1WR04501VA	TAN-51 (240)	19-Aug-02
1WR05201VA	TAN-51 (460)	20-Aug-02
1WR05301VA	TAN-51 (342B)	20-Aug-02
1WR04901VA	TAN-51 (342)	20-Aug-02
1WR04902VA	TAN-51 (342)	20-Aug-02
1WR07201VA	TAN-54 (420)	21-Aug-02
1WR17201VA		
1WR17201VA	Trip Blank	8-Jul-02
1WR17301VA	Rinsate	11-Jul-02
1WR01901VA	TAN-15	11-Jul-02
1WR01701VA	TAN-50	11Jul-02
1WR00101VA	TAN-11	11-Jul-02

Table E-1. (continued).

Sample Delivery Group Sample ID	Location	Date
1WR09101	Trip Blank	8-Jul-02
1WR03201VA	TAN-56	9-Jul-02
1WR03301VA	TAN-57	8-Jul-02
1WR08501VA	PE Sample	9-Jul-02
1WRO2101VA		
1WR02101VA	TAN-22A	15-Jul-02
1WR16801VA	Field Blank	15-Jul-02
1WR17401VA	Rinsate	15-Jul-02
1WR09201VA	Trip Blank	15-Jul-02
1WR17701VE	TAN-32	16-Jul-02
1WR02001VA		
1WR02001VA	TAN-16	22-Jul-02
1WR02201VA	TAN-23A	22-Jul-02
1WR17901VA	Trip Blank	18-Jul-02
1WR01601VE	TAN-47	18-Jul-02
1WR01801VA	TAN-D1	23-Jul-02
1WR16901VA	Field Blank	22-Jul-02
1WR17501VA	Rinsate	22-Jul-02
1WR09401VA		
1WR09401VA	Trip Blank	19-Aug-02
1WR0702VA	TAN-54 (373)	21-Aug-02
1WR07001VA	TAN-54 (373)	21-Aug-02
1WR06891VA	TAN-54 (330.5)	21-Aug-02
1WR06901VA	TAN-54 (347)	21-Aug-02
1WR06701VE	TAN-54 (318)	21-Aug-02
1WR09601VA		
1WR09601VA	Trip Blank	3-Sept-02
1WR05401VA	TAN-52 (220)	3-Sept-02
1WR05501VA	TAN-52 (242)	3-Sept-02
1WR05901VA	TAN-52 (373)	3-Sept-02
1WR06001VA	TAN-52 (395)	4-Sept-02
1WR06101VA	TAN-52 (438)	4-Sept-02
1WR06201VA	TAN-52 (456)	4-Sept-02
1WR06301VA	TAN-52 (266)	4-Sept-02
1WR08301VA	TAN-55 (461)	4-Sept-02
1WR08201VA	TAN-55 (449)	4-Sept-02
1WR06501VA	TAN-52 (438)	4-Sept-02
1WR06401VA	TAN-52 (373)	4-Sept-02
1WR05902VA	TAN-52 (373)	3-Sept-02
1WR05801VA	TAN-52 (361)	3-Sept-02
1WR05701VA	TAN-52 (303)	3-Sept-02
1WR05601VA	TAN-52 (266)	3-Sept-02
1WR04601VA		
1WR04601VA	TAN-51 (263)	19-Aug-02
1WR04801VA	TAN-51 (322)	20-Aug-02
1WR05101VA	TAN-51 (413)	20-Aug-02
1WR07301VA	TAN-54 (460)	21-Aug-02
1WR04701VA	TAN-51 (283.5)	20-Aug-02
1WR07101VA	TAN-54 (394)	21-Aug-02
1WR06601VA	TAN-54 (234)	21-Aug-02
1WR17001VA	Field Blank	21-Aug-02
1WR00801VA		
1WR00801VA	TAN-04	15-Oct-02
1WR02401VA	GIN-2	15-Oct-02
1WR02402VA	GIN-2	15-Oct-02
1WR02501VA	GIN-4	15-Oct-02
1WR18101VA	Trip Blank	15-Oct-02
1WR17101VA	Field Blank	15-Oct-02

Table E-2. Sample delivery groups and samples collected for radioloaical analvsis.

Sample Delivery Group / Sample ID	Location (Depth)	Date
1WR00201RB		
1WR00901RB	USGS-24	25-Jun-02
1WR00201RB	TAN-D3	26-Jun-02
1WR00301RB	TAN-34	26-Jun-02
1WR00501RB	TAN-19	16-Jun-02
1WR01101RB	TAN-02	25-Jun-02
1WR09901RB	Field Blank	25-Jun-02
1WR01301RB	TAN-13A	17-Jun-02
1WR01302RB	TAN-13A	17-Jun-02
1WR00901RB	TAN-05	19-Jun-02
1WR01201RB	TAN-03	12-Jun-02
1WR01401RB	TAN-14	12-Jun-02
1WR09801RB	Field Blank	17-Jun-02
1WR00201R8		
1WR09801R8	Field Blank	17-Jun-02
1WR03001R8	TAN-08	17-Jun-02
1WR01302R8	TAN-13A	17-Jun-02
1WR03101R8	TAN-17	17-Jun-02
1WR02901R8	TAN-07	17-Jun-02
1WR01301R8	TAN-13A	17-Jun-02
1WR00301R8	TAN-34	26-Jun-02
1WR00201R8	TAN-D3	26-Jun-02
1WR009901R8	Field Blank	25-Jun-02
1WRO1101R8	TAN-02	25-Jun-02
1WROO601R8	USGS-24	25-Jun-02
1WR02701R8	MW-2	10-Jun-02
1WR02801R8	TAN-06	10-Jun-02
1WR02601R8	TAN-24A	10-Jun-02
1WR01401R8	TAN-14	12-Jun-02
1WR01201R8	TAN-03	12-Jun-02
1WR00501R8	TAN-19	19-Jun-02
1WR00901R8	TAN-05	19-Jun-02
1WR03401R8	TAN-58	20-Jun-02
1WR08501RB		
1WR17501RB	Rinsate	22-Jul-02
1WR16801RB	Field Blank	15-Jul-02
1WR17201RB	Field Blank	8-Jul-02
1WR16901RB	Field Blank	22-Jul-02
1WR08501RB	PE Sample	11-Jul-02
1WR17501R8	Rinsate	22-Jul-02
1WR16801R8	Field Blank	15-Jul-02
1WR08501R8	PE Sample	11-Jul-02
1WR16901R8	Field Blank	22-Jul-02
WR17001RB		
1WR17001RB	Field Blank	21-Aug-02
1WR04501R8		
1WR17001R8	Field Blank	21-Aug-02
1WR07001R8	TAN-54 (373)	21-Aug-02
1WR05101R8	TAN-51 (413)	20-Aug-02
1WR04902R8	TAN-51 (342)	20-Aug-02
1WR04701R8	TAN-51 (283.5)	20-Aug-02
1WR04901R8	TAN-51 (342)	20-Aug-02
1WR07101R8	TAN-54 (394)	21-Aug-02
1WR07301R8	TAN-54 (460)	21-Aug-02
1WR07002R8	TAN-54 (373)	21-Aug-02
1WR07201R8	TAN-54 (420)	21-Aug-02
1WR06601R8	TAN-54 (234)	21-Aug-02
1WR06801R8	TAN-54 (330.5)	21-Aug-02
1WR06701R8	TAN-54 (318)	21-Aug-02
1WR03601RB		
1WR07601R8	TAN-55 (265)	28-Aug-02
1WR17601RB	Rinsate	28-Aug-02
1WR03601RB	TAN-48 (273)	26-Aug-02
1WR07901R8	TAN-55 (373.5)	28-Aug-02
1WR07401R8	TAN-55 (221)	27-Aug-02
1WR03701R8	TAN-48 (317)	26-Aug-02
1WR07701R8	TAN-55 (317)	28-Aug-02
1WR17601R8	Rinsate	28-Aug-02
1WR04001R8	TAN-48 (412)	26-Aug-02
1WR04201R8	TAN-48 (225)	27-Aug-02
1WR07801R8	TAN-55 (332)	28-Aug-02
1WR04301R8	TAN-48 (273)	27-Aug-02
1WR03901R8	TAN-48 (381)	26-Aug-02
1WR00701RB		
1WR16701RB	Field Blank	1-Jul-02
1WR16701R8	Field Blank	1-Jul-02
1WR17301RB	Rinsate	11-Jul-02
1WR17301R8	Rinsate	11-Jul-02

Table E-2. (continued)

Sample Delivery Group Sample ID	Location (Depth)	Date
1WR00701RB	TAN-32	1-Jul-02
1WR00701R8	TAN-32	1-Jul-02
1WR01601RB	TAN-47	18-Jul-02
1WR01601R8	TAN-47	18-Jul-02
1WR08401RB	PE Sample	17-Jul-02
1WR08401R8	PE Sample	17-Jul-02
1WR00101RB		
1WR17401RB	Rinsate	15-Jul-02
1WR00101RB	TAN-11	11-Jul-02
1WR01701RB	TAN-50	11-Jul-02
1WR01801RB	TAN-D1	23-Jul-02
1WR08601RB	PE Sample	27-JLUI-02
1WR01801R8	TAN-D1	23-Jul-02
1WR08601R8	PE Sample	27-JLUI-02
1WR01701R8	TAN-50	11-Jul-02
1WR00101R8	TAN-11	11-Jul-02
1WR02201R8	TAN-23A	22-Jul-02
1WR02101R8	TAN-22A	15-Jul-02
1WR01901R8	TAN-15	11-Jul-02
1WR17201R8	Field Blank	8-Jul-02
1WR17401R8	Rinsate	15-Jul-02
1WR03201R8	TAN-56	9-Jul-02
1WR02001R8	TAN-16	22-Jul-02
1WR03301R8	TAN-57	8-Jul-02
1WR02301R8	TAN-21	1-Jul-02
1WR03501R8		
1WR07602R8	TAN-55 (265)	28-Aug-02
1WR03801R8	TAN-48 (345)	26-Aug-02
1WR03802R8	TAN-48 (345)	26-Aug-02
1WR08001R8	TAN-55 (404)	28-Aug-02
1WR04401R8	TAN-48 (381)	27-Aug-02
1WR03601R8	TAN-48 (273)	26-Aug-02
1WR03501R8	TAN-48 (225)	26-Aug-02
1WR08101R8	TAN-55 (439)	28-Aug-02
1WR07501R8	TAN-55 (251)	27-Aug-02
1WR04101R8	TAN-48 (431)	27-Aug-02
1WR04601R8	TAN-51 (263)	19-Aug-02
1WR06901R8	TAN-54 (347)	21-Aug-02
1WR05201R8	TAN-51 (460)	20-Aug-02
1WR05001R8	TAN-51 (367)	20-Aug-02
1WR05301R8	TAN-51(342B)	20-Aug-02
1WR04801R8	TAN-51 (322)	20-Aug-02
1WR04501R8	TAN-51 (240)	19-Aug-02
1WR00402RB		
1WR00401RB	TAN-18	2-Oct-02
1WR00401R8	TAN-18	2-Oct-02
1WR00801RB		
1WR00801R8	TAN-04	15-Oct-02
1WR00801RB	TAN-04	15-Oct-02
1WR02401R8	GIN-2	15-Oct-02
1WR02402R8	GIN-2	15-Oct-02
1WR02501R8	GIN-4	15-Oct-02
1WR17101RB	Field Blank	15-Oct-02
1WR17101R8	Field Blank	15-Oct-02

Appendix F

Planned Versus Performed Sampling for Fiscal Year 2002

Appendix F

Planned Versus Performed Sampling for Fiscal Year 2002

Table F-1. Planned versus performed sampling for Fiscal Year 2002.

		Sampling Planned / Performed					
Location	Depth	Date	^{3}H	^{90}Sr	VOCs	VOCs MS/MSD	Notes
ANP-8	268	NA	1/0	—	1/0	—	No access
GIN-2	368	10/15/02	2/2	—	2/2	—	—
GIN-4	290	10/15/02	1/1	—	1/1	—	—
Mw-2	236	6/10/02	1/1	—	1/1	—	—
TAN-01	280	NA	1/0	1/0	1/0	—	No access
TAN-02	335	6/25/02	1/1	1/1	1/1	—	—
TAN-03	252	6/12/02	1/1	1/1	1/1	—	—
TAN-04	235	10/15/02	1/1	1/1	1/1	—	—
TAN-05	297	6/19/02	1/1	1/1	—	1/1	—
TAN-06	240	6/10/02	1/1	—	1/1	—	—
TAN-07	300	6/17/02	1/1	—	1/1	—	—
TAN-08	231	6/17/02	1/1	—	1/1	—	—
TAN-10A	233	8/5/02	1/1	—	1/1	—	—
TAN-11	301	7/11/02	1/1	1/1	1/1	—	—
TAN-13A	221	6/17/02	2/2	2/2	2/2	—	—
TAN-14	378	6/12/02	1/1	1/1	1/1	—	—
TAN-15	238	7/11/02	1/1	—	1/1	—	—
TAN-16	306	7/22/02	1/1	—	1/1	—	—
TAN-17	337	6/17/02	1/1	—	—	1/1	—
TAN-18	500	10/2/02	1/1	1/1	1/1	—	—
TAN-19	404	6/19/02	1/1	1/1	1/1	—	—
TAN-21	440	7/25/02	1/1	—	1/2	—	See note below
TAN-22A	520	7/15/02	1/1	—	1/1	—	—
TAN-23A	440	7/22/02	1/1	—	1/1	—	—
TAN-24A	231	6/10/02	1/1	—	1/1	—	—
TAN-25	218	8/5/02	1/1	1/1	1/1	—	—
TAN-26	389	8/5/02	1/1	1/1	1/1	—	—
TAN-27	235	8/5/02	1/1	—	1/1	—	—
TAN-28	240	8/5/02	1/1	1/1	1/1	—	—
TAN-29	255	6/3/02	1/1	1/1	1/1	—	—
TAN-30A	310	8/5/02	1/1	—	1/1	—	—
TAN-31	258	8/5/02	1/1	1/1	1/1	—	—
TAN-33	289	6/5/02	2/2	2/2	2/2	—	—
TAN-32	250	7/16/02	1/1	1/1	1/1	—	—
TAN-34	310	6/26/02	1/1	1/1	1/1	—	—
TAN-36	296	6/5/02	2/2	2/2	2/2	—	—

Table F-1. (continued)

Location	Depth	Sampling Planned / Performed					Notes
		Date	^{3}H	^{90}Sr	VOCs	VOCs MS/MSD	
TAN-37	240	8/5/02	1/1	—	1/1	—	—
TAN-43	299	6/5/02	1/1	1/1	1/1	—	—
TAN-44	295	6/5/02	2/2	2/2	2/2	—	—
TAN-47	270	7/18/02	1/1	1/1	—	1/1	—
TAN-48	225	8/26/02	1/1	—	1/1	—	—
TAN-48	273	8/26/02	1/1	1/1	1/1	—	—
TAN-48	317	8/26/02	1/1	—	1/1	—	—
TAN-48	345	8/26/02	2/2	—	2/2	—	—
TAN-48	381	8/26/02	1/1	—	1/1	—	—
TAN-48	412	8/26/02	1/1	—	1/1	—	—
TAN-48	431	8/27/02	1/1	—	1/1	—	—
TAN-48	225	8/27/02	1/1	—	1/1	—	Repeat sample
TAN-48	273	8/27/02	1/1	—	1/1	—	Repeat sample
TAN-48	381	8/27/02	1/1	—	1/1	—	Repeat sample
TAN-50	438	7/11/02	1/1	1/1	1/1	—	—
TAN-51	240	8/19/02	1/1	—	1/1	—	—
TAN-51	263	8/19/02	1/1	—	1/1	—	—
TAN-51	283.5	8/20/02	1/1	—	1/1	—	—
TAN-51	322	8/20/02	1/1	—	1/1	—	—
TAN-51	342	8/20/02	2/2	—	2/2	—	—
TAN-51	367	8/20/02	1/1	—	1/1	—	—
TAN-51	413	8/20/02	1/1	—	1/1	—	—
TAN-51	460	8/20/02	1/1	—	1/1	—	—
TAN-51	342B	8/20/02	1/1	—	1/1	—	—
TAN-52	220	9/3/02	1/1	—	1/1	—	—
TAN-52	242	9/3/02	1/1	—	1/1	—	—
TAN-52	266	9/3/02	1/1	—	1/1	—	—
TAN-52	303	9/3/02	1/1	—	1/1	—	—
TAN-52	361	9/3/02	1/1	—	1/1	—	—
TAN-52	373	9/3/02	2/2	—	2/2	—	—
TAN-52	395	9/4/03	1/1	—	1/1	—	—
TAN-52	438	9/4/02	1/1	—	1/1	—	—
TAN-52	456	9/4/02	1/1	—	1/1	—	—
TAN-52	266	9/4/02	1/1	—	1/1	—	Repeat sample
TAN-52	373	9/4/02	1/1	—	1/1	—	Repeat sample
TAN-52	438	9/4/02	1/1	—	1/1	—	Repeat sample
TAN-54	234	8/21/02	1/1	—	1/1	—	—
TAN-54	318	8/21/02	1/1	—	—	1/1	—
TAN-54	330.5	8/21/02	1/1	—	1/1	—	—
TAN-54	347	8/21/02	1/1	—	1/1	—	—
TAN-54	373	8/21/02	2/2	—	2/2	—	—

Table F-1. (continued)

Location	Depth	Sampling Planned / Performed					Notes
		Date	^{3}H	^{90}Sr	VOCs	VOCs MS/MSD	
TAN-54	394	8/21/02	1/1	—	1/1	—	—
TAN-54	420	8/21/02	1/1	—	1/1	—	—
TAN-54	460	8/21/02	1/1	—	1/1	—	—
TAN-55	221	8/27/02	1/1	—	1/1	—	—
TAN-55	251	8/27/02	1/1	—	1/1	—	—
TAN-55	265	8/28/02	2/2	—	2/2	—	—
TAN-55	317	8/28/02	1/1	—	1/1	—	—
TAN-55	332	8/28/02	1/1	—	1/1	—	—
TAN-55	373.5	8/28/02	1/1	—	1/1	—	—
TAN-55	404	8/28/02	1/1	—	1/1	—	—
TAN-55	439	8/28/02	1/1	—	1/1	—	—
TAN-55	449	9/4/02	1/1	—	1/1	—	—
TAN-55	461	9/4/02	1/1	—	1/1	—	—
TAN-56	343	7/9/02	1/1	—	1/1	—	—
TAN-57	353	7/8/02	1/1	—	1/1	—	—
TAN-58	295	6/20/02	1/1	—	—	1/1	—
TAN-D1	300	7/23/02	1/1	1/1	1/1	—	—
TAN-D2	241	8/5/02	1/1	—	1/1	—	—
TAN-D3	257	6/26/02	1/1	1/1	1/1	—	—
TSF-05	289	8/6/02	1/1	1/1	1/1	—	—
USGS-24	260	6/25/02	1/1	1/1	1/1	—	—
PES	—	6/26/02	—	—	1/1	—	—
PES"	—	7/9/02	—	—	1/1	—	—
PES	—	7/17/02	—	1/1	—	—	—
PES	—	7/17/02	1/1	—	—	—	—
PES	—	6/27/02	1/1	—	—	—	—
PES	—	6/27/02	—	1/1	—	—	—
PES	—	7/11/02	—	1/1	—	—	—
PES	—	7/11/02	1/1	—	—	—	—
QC[b] Trip Blank	—	6/10/02	—	—	1/1	—	—
QC Trip Blank	—	6/20/02	—	—	1/1	—	—
QC Trip Blank	—	6/17/02	—	—	1/1	—	—
QC Trip Blank	—	7/8/02	—	—	1/1	—	—
QC Trip Blank	—	7/8/02	—	—	1/1	—	—
QC Trip Blank	—	7/15/02	—	—	1/1	—	—
QC Trip Blank	—	7/18/02	—	—	1/1	—	—
QC Trip Blank	—	7/25/02	—	—	1/1	—	—
QC Trip Blank	—	8/19/02	—	—	1/1	—	—
QC Trip Blank	—	8/26/02	—	—	1/1	—	—
QC Trip Blank	—	9/3/02	—	—	1/1	—	—
QC Trip Blank	—	10/15/02	—	—	1/1	—	—

Table F-1. (continued)

Location	Depth	Sampling Planned / Performed: Date	^{3}H	^{90}Sr	VOCs	VOCs MS/MSD	Notes
QC Field Blank	—	6/25/02	—	—	1/1	—	—
QC Field Blank	—	6/17/02	—	—	1/1	—	—
QC Field Blank	—	7/15/02	—	—	1/1	—	—
QC Field Blank	—	7/22/02	—	—	1/1	—	—
QC Field Blank	—	8/21/02	—	—	1/1	—	—
QC Field Blank	—	10/15/02	—	—	1/1	—	—
QC Field Blank	—	6/25/02	—	1/1	—	—	—
QC Field Blank	—	6/17/02	—	1/1	—	—	—
QC Field Blank	—	6/17/02	1/1	—	—	—	—
QC Field Blank	—	6/25/02	1/1	—	—	—	—
QC Field Blank	—	7/1/02	—	1/1	—	—	—
QC Field Blank	—	7/1/02	1/1	—	—	—	—
QC Field Blank	—	7/8/02	1/1	—	—	—	—
QC Field Blank	—	7/15/02	—	1/1	—	—	—
QC Field Blank	—	7/8/02	—	1/1	—	—	—
QC Field Blank	—	7/22/02	—	1/1	—	—	—
QC Field Blank	—	7/15/02	1/1	—	—	—	—
QC Field Blank	—	7/22/02	1/1	—	—	—	—
QC Field Blank	—	8/21/02	—	1/1	—	—	—
QC Field Blank	—	8/21/02	1/1	—	—	—	—
QC Field Blank	—	10/15/02	—	1/1	—	—	—
QC Field Blank	—	10/15/02	1/1	—	—	—	—
QC Rinsate	—	7/11/02	—	—	1/1	—	—
QC Rinsate	—	7/15/02	—	—	1/1	—	—
QC Rinsate	—	7/22/02	—	—	1/1	—	—
QC Rinsate	—	8/28/02	—	—	1/1	—	—
QC Rinsate	—	7/11/02	—	1/1	—	—	—
QC Rinsate	—	7/11/02	1/1	—	—	—	—
QC Rinsate	—	7/15/02	1/1	—	—	—	—
QC Rinsate	—	7/15/02	—	1/1	—	—	—
QC Rinsate	—	7/22/02	—	1/1	—	—	—
QC Rinsate	—	7/22/02	1/1	—	—	—	—
QC Rinsate	—	8/28/02	1/1	—	—	—	—
QC Rinsate	—	8/28/02	—	1/1	—	—	—

Note: Shaded cells indicate deviations from planned activities.
The VOC sample was collected from TAN-21 on July 1, 2002, and was compromised by the laboratory on July 9, 2002, by improperly opening the sample container to check the pH. The well was resampled on July 25, 2002, when a replacement sample and duplicate were taken as per revision 13 of Sample Analysis Plan (SAP) # INEEL/EXT-99-21.
a. PES: performance evaluation samples (see section 6.5.)
b. QC: quality control (see section 6 and Appendix D)